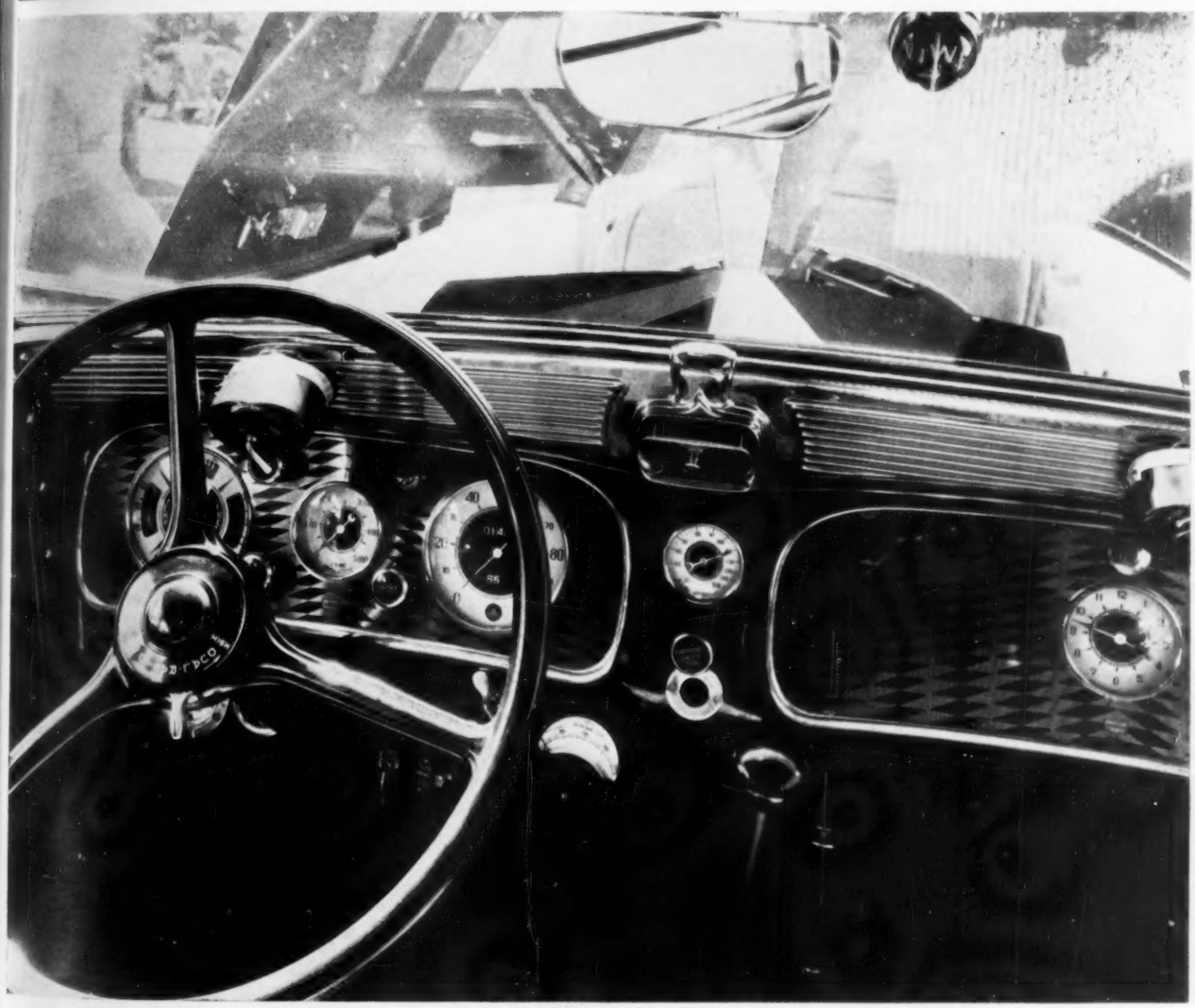
SEP 27 1935

INSTRUMENTS

THE MAGAZINE OF

MEASUREMENT AND CONTROL

Volume 8 SEPTEMBER 1935 Number 9



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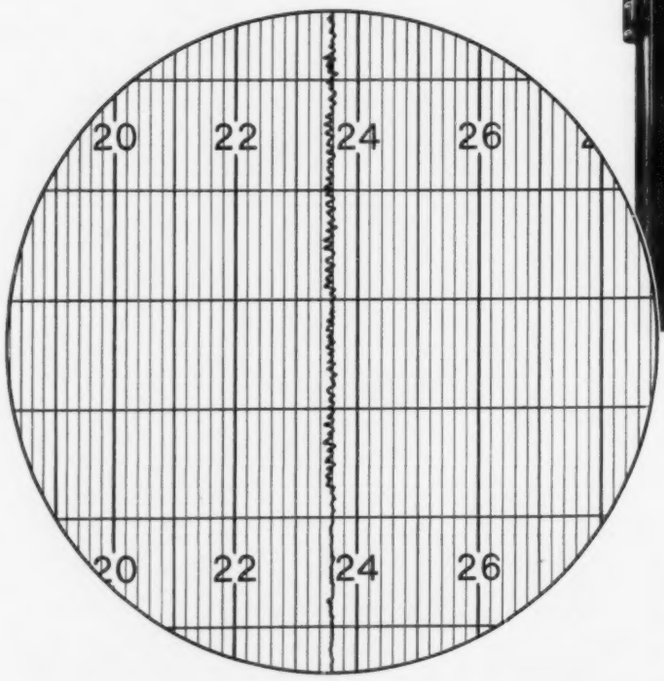

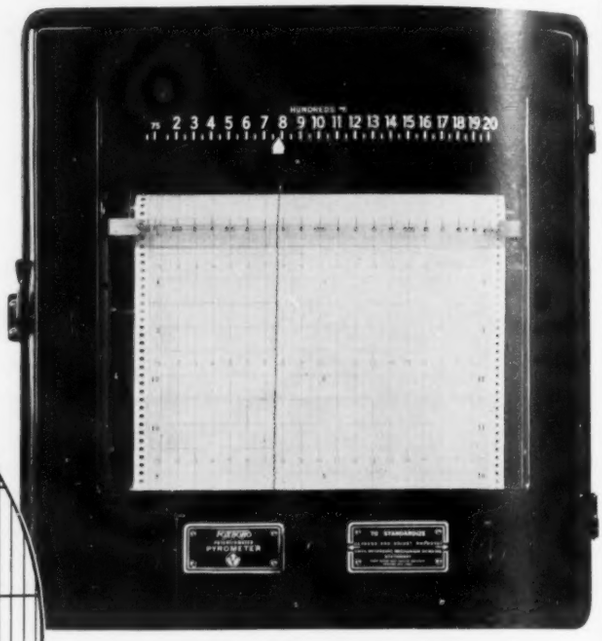

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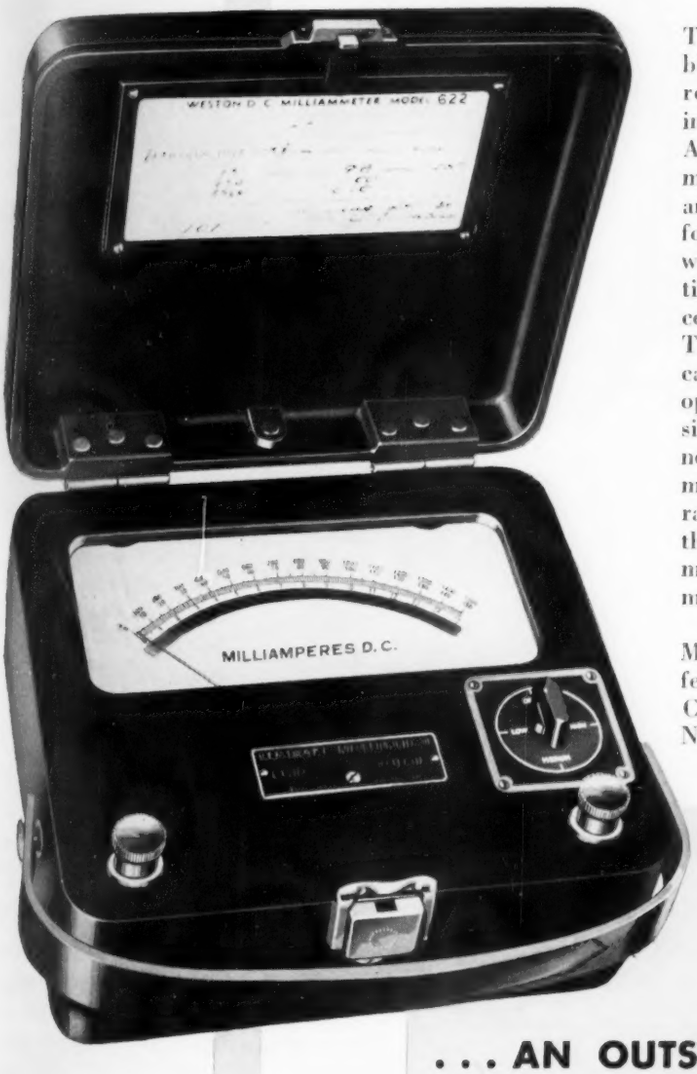

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INSTRUMENTS
THE MAGAZINE of MEASUREMENT and CONTROL

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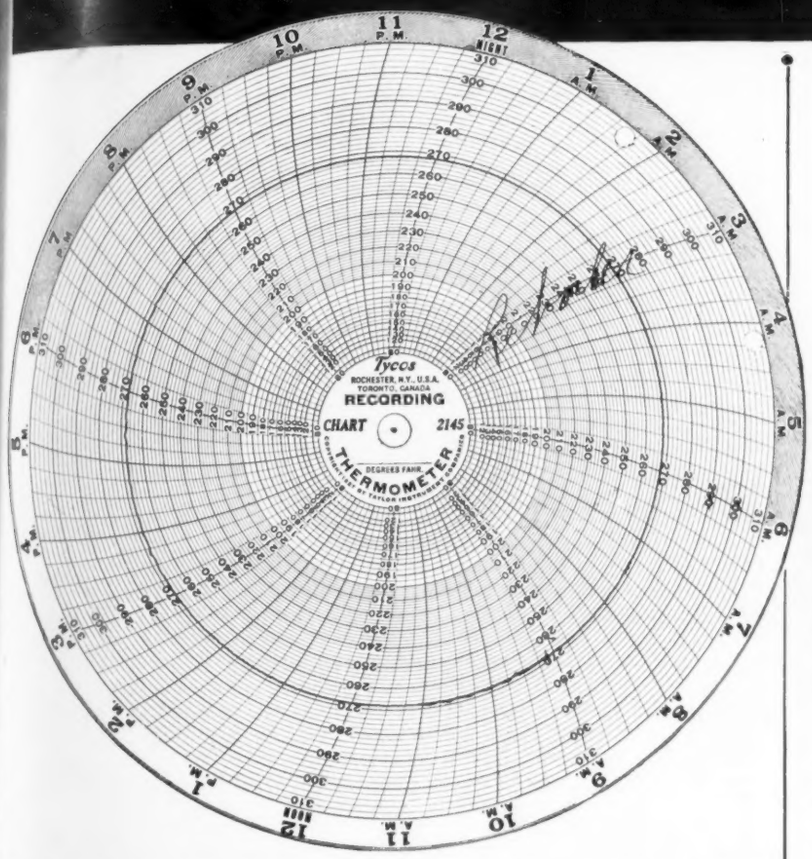
HOW TO ASSURE PRECISION CONTROL

of reboiler temperature



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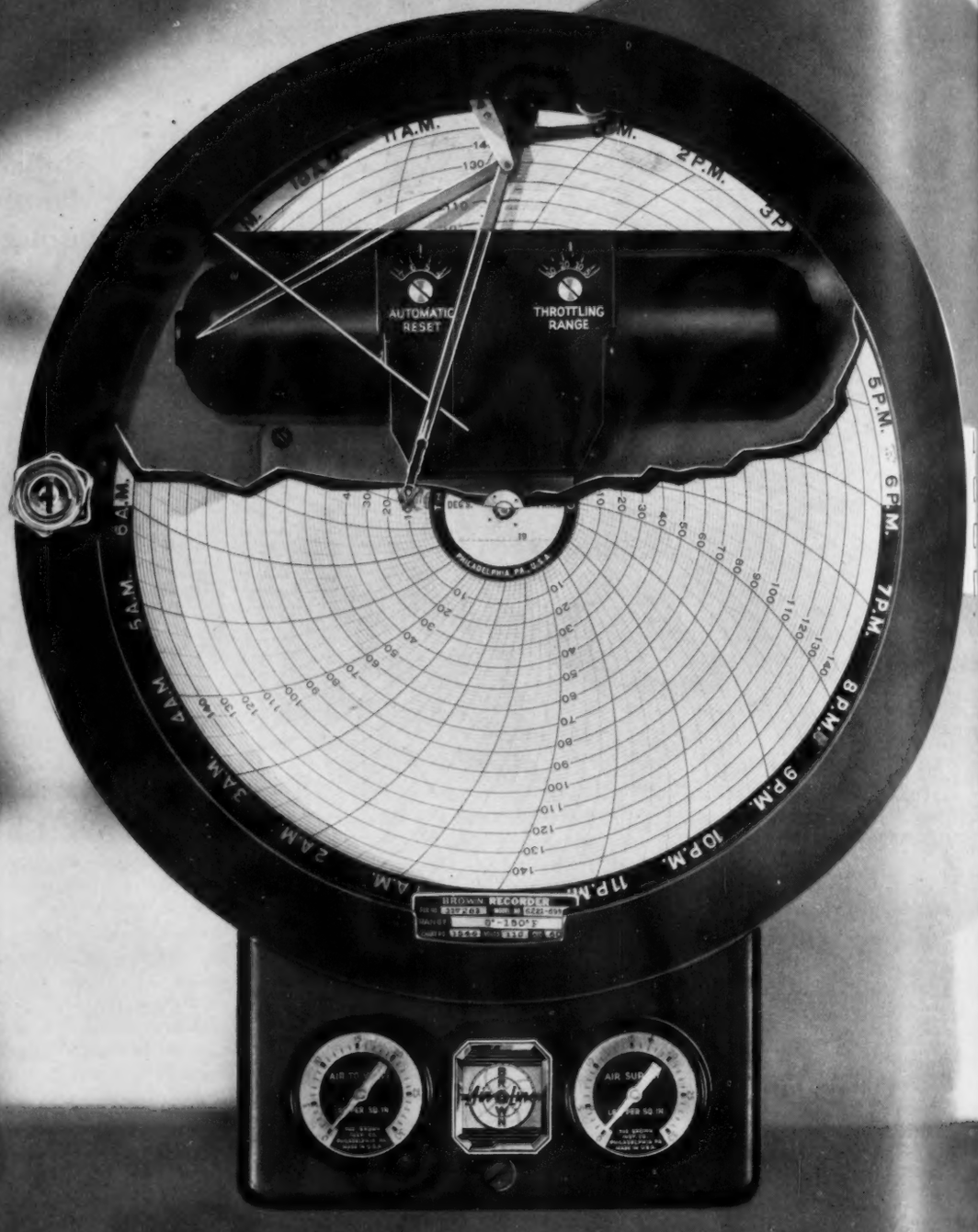

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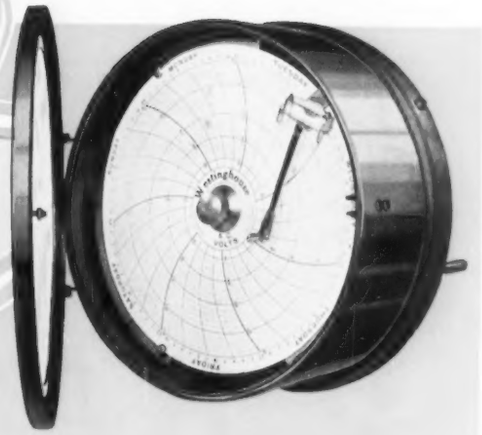

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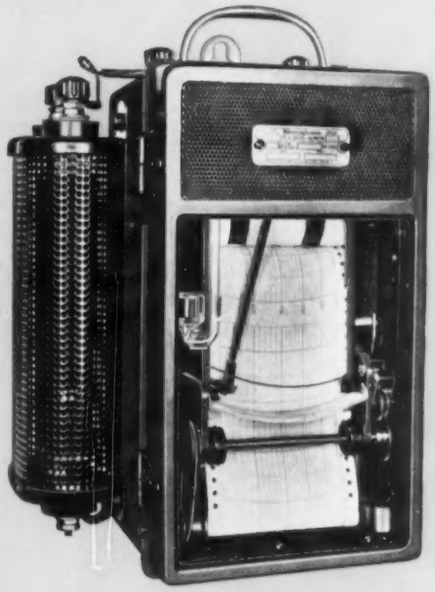

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★ ★ ★ ★

For more detailed information about these two recorders ask for C.S. 43-415, Type A Recording Instruments, and C.S. 43-405, Type U Recording Ammeters and Voltmeters.

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430-51

GENERAL ELECTRIC

EDITORIAL COMMENT

In This Issue

Although not stated in the finally-approved draft of this month's leading article, the new method described therein was developed by F. C. Rushing and J. G. Baker, both of Westinghouse Research Laboratories—and both modest!

The Tuve-Sprenkle "Authors' Closure" closes a series which constitutes a distinct contribution to the metering of oils and other viscous fluids.

The Manual of Instrumentation having appeared serially in *Instruments* since January 1930, you may have noticed that one of its purposes is to establish rational classifications. In some cases, instruments that look alike have been assigned to different chapters or sections; in other cases, the hidden similarities of instruments or systems (which appeared to be wholly different by reason of all previous descriptions and of all previous diagrams) are brought out by new wordings of descriptions and by new diagrams, especially written and drawn for our Manual with the hearty approval of prominent manufacturers. Sometimes, the manufacturers themselves have been surprised.

R. R. Batcher completes his pair of articles on deflection methods, preparatory to discussing internal electrode arrangements next month.

The front-cover photograph was received from the Illinois Testing Laboratories, makers of the engine pyrometer used on the much-heralded Auburn stock model phaeton-sedan equipped with a Cummins Diesel engine which C. L. Cummins drove coast-to-coast on less than $8 for fuel.

ERRATUM

On page 204 of our last issue, in the second line under the first two equations, "Equation (2)" should be "Equation (1)."

It's a Pleasure to Serve You

THIS is the time of the year when inquiries pertaining to repairing and replacing instruments and meters keep our staff busy looking up cards, making out individual lists, and copying questions to be transmitted to specialists outside this office. In spite of the rush, and although the employees who are not engineering graduates are highly competent, every inquiry is personally handled by either the Managing Editor or by the Editor. It's a pleasure to serve you, so if you have any questions on your mind, don't hesitate to send them in.

After six years of enjoying this pleasure, one notes a fairly definite frequency distribution of types of inquiries. Therefore, a few bits of general advice are well worth repeating:

Repairing or replacing "old" instruments. Depends on class, type, service, etc. A 30-year-old compressed-air gage (required accuracy $\pm 2\%$) may only need cleaning and the right lubricant; a year-old laboratory Standard ammeter (required accuracy $\pm 0.2\%$) which was abused should be replaced.

Repair cost vs. cost of new instrument. Unless repair costs are trifling, consider getting new instruments. In any event, have maker supply data on his new models.

Trade-ins. It may pay to trade in a number of perfectly serviceable old devices for new models possessing improved characteristics. This applies especially to automatic controllers and auxiliaries such as air or electric valve-operating devices, designed to cut processing costs.

"Bootleg" parts. These usually impair the sensitivity and accuracy of instruments. (Especially true of springs.)

Re-filling tube-systems. Unless the same quantity of the same fluid is put in under the same conditions, the scale law will be altered. Beware of unrecognized repair shops where vapor-pressure systems are "evacuated" by heating the bulb, where alcohol is substituted for nitrogen, where pressure-springs are dipped in acid to increase the deflection, and where guess-work is inevitable for want of the maker's factory instructions.

Orifice plates, nozzles, Venturis and Pitot tubes. Don't let the average pipe-fitter touch these. Don't even let the flange bolts be loosened until instructions are at hand. Forbid the use of files or abrasives.

Mercury in manometers, etc. (elsewhere than in vacuum seals) requires periodical purification or replacement.

Second-hand instruments. If your financial overlords compel you to buy these, don't buy them from other sources than instrument makers who give guarantees.

Some day, we may compile a sort of guide made up of questions and answers. Meanwhile, keep on sending in your questions, for it's a pleasure to serve you!

M. F. BEHAR

A Rapid Method for Determining and Correcting Unbalance

as told by
F. C. RUSHING*

I. STATEMENT OF THE PROBLEM

ELIMINATION of appreciable vibrations, and reduction of noise to nearly the threshold of audibility, are being demanded in an ever-increasing number of fields of manufacture. In engineering terms this demand necessitates a closer approach to perfection in the balancing of rotating parts. Consideration shows the specific requirement to be for a higher degree of accuracy in the dynamic balance of each rotor at its operating speed. This definite objective has heretofore been comparatively difficult in the quantity production of such products as household motor-driven devices, office machines, shop equipment, automobiles, etc. It is in these very classes of products that one finds high-speed rotors; and with high-speed rotors both the requisite precision in *determining* the amount and position of unbalance, and the requisite accuracy in *correcting* it sufficiently to minimize noise and vibration, can best be attained by balancing at operating speed. The reason is easily demonstrated as follows: First, assume an ideally *rigid* rotor, its normal operating speed being either fast or slow. It is known that the total unbalance of such a rotor can be resolved into effective unbalance components lying in two arbitrarily chosen planes perpendicular to its axis of rotation; hence by suitable increments or decrements of mass in these two planes the rotor can be balanced both statically and dynamically; *i.e.*, for any speed. Consider next a *non-rigid* rotor. The two-plane analysis applies equally here, but each solution applies only to one speed of rotation; amounts and positions of mass increments or decrements in the correction planes depend on the speed. Since no rotor is ideally rigid, since centrifugal forces are proportional to the square of angular velocity, and since asymmetrical distortions are present at high speeds in all rotors (and even at low speeds in long rotors and single-bearing rotors), the speed at which a high-speed rotor is to be balanced dynamically must not differ appreciably from its operating speed.

Another element of the problem is that inspection time being charged as manufacturing cost, slow methods of determining and correcting unbalance are prohibitively expensive in those lines of manufacture where competition dictates the price levels. A further disadvantage of slow methods is the variability of the time required for doing a good job (source of irritation to both management and skilled labor).

Another frequent requirement is for determining and correcting the unbalance of a rotor in its own bearings—at operating speed and with minimal expenditure of time.

The problem imposed on manufacturers by the strong public preference for silent and vibrationless machines having thus been expressed in specific engineering requirements, the conclusion was obvious that its complete solution called for balancing all rotors manufactured, which in turn required the development of a method combining (1) rapidity, (2) extreme accuracy of determination and correction, (3) suitability for balancing any rotor at its operating speed, (4) practicability of balancing large rotors in their own bearings at operating speed, and (5) physical embodiment in a simple apparatus to be operated by factory labor in the case of quantity-production rotors and by junior engineers in the case of large turbo-generators, etc.

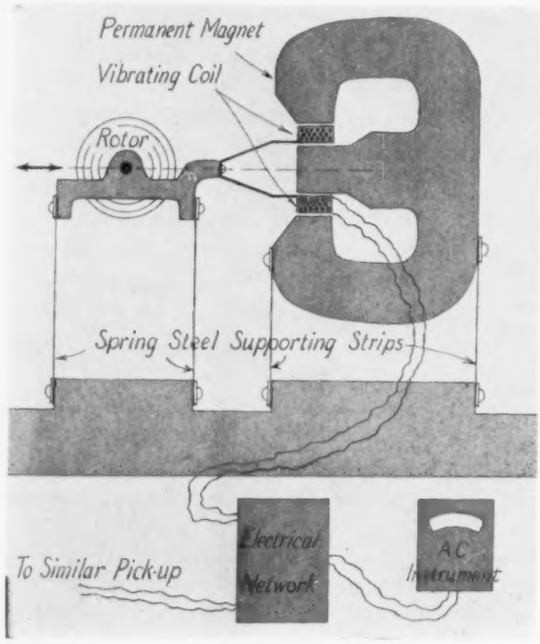

Fig. 1. Schematic sketch showing fundamental principle of Electro-Network balancing method.

Item 5 could also be expressed in terms of the instrument readings: the *amount* of unbalance in each of two correction planes is to be indicated on a dial calibrated in grams or ounces, and the *positions* of the two requisite mass increments or decrements are likewise to be shown to the operator by automatic pointers or their equivalent.

All five of these requirements are met by the new method described in this article, which was developed in the course of a year of experimental work at the Westinghouse Research Laboratories, followed by six months of trial applications to actual factory production. Successful applications of the new method have been made for small rotors from 1¼″ to 3″ diameter; for medium-sized rotors up to 100 lbs. in weight; and for very large turbo-generator rotors. Speeds of balancing range from 1200 to 1800 r.p.m. (with one exception in which the balancing speeds are from 6000 to 8000 r.p.m.).

High-speed rotors are mounted in bearings similar to their own; very large rotors are balanced in their own bearings.

The new method was used with good results on May 11, 1935, in balancing the largest turbo-generator rotor ever constructed (weight 250,000 lbs.).

*Westinghouse Research Laboratories, East Pittsburgh, Pa.

2. BRIEF COMPARISON OF EXISTING METHODS AND NEW METHOD

Of the methods in use for determining unbalance corrections, the most primitive consists in flexibly mounting the rotor and adding or subtracting weight by trial until the mounting or rotor ceases to vibrate during rotation. It is seldom applicable in quantity production and need not be discussed.

Various types of Balancing Machines have been built for determining, without calculation but correctly, the amount and position of unbalance effect in each of the two correction planes. In general such machines consist of a flexibly restrained carriage, pivoted or effectively pivoted about an axis or point contained in one of the correction planes, in which the rotor to be balanced may be rotated; in combination with either: (1) an arrangement for measuring the amount and phase with respect to rotation of the motion of this carriage; or (2) means of introducing a known unbalance effect on the carriage adjustable or variable both in phase or in amount.

The pivoted carriage common to all balancing machines has for its function the separation of the unbalance components in the two correction planes. This is accomplished by having the pivot of the carriage lie in one of the balancing planes, so that any force caused by an unbalance in this plane is directed through the pivot and therefore cannot affect the rotary motion of the carriage about the pivot. The distinctive feature of the new method is that no pivoted carriage is required. The rotor may be mounted in almost any way so long as the unbalance components at both correction planes produce vibration of the rotor or mounting. This feature permits the balancing of rotors in their own bearings, and otherwise allows freedom in mounting design not obtained with the pivoted carriage.

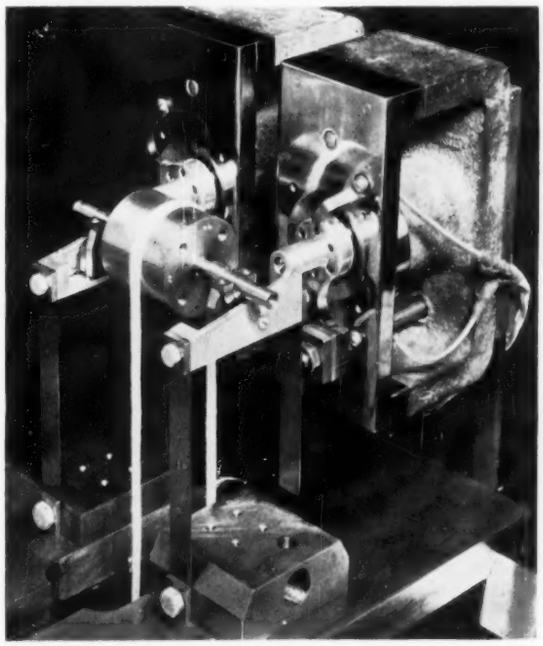

Fig. 2. Actual construction of rotor mounting and magnetic pick-ups of balancing equipment.

The balancing at operating speed of high-speed rotors (which distort asymmetrically) is difficult in a pivoted carriage because distortion in the carriage tends to displace the point of actual pivoting from that intended, and because the large forces caused by the high-speed rotation of an unbalanced rotor in a pivoted carriage result in serious vibration problems. With the new method, no such carriage problem is involved, and the mechanical design may be made that which is most suitable for rotation of the unbalanced rotor at the desired high speed.

Although the new method was developed primarily with regard to balancing problems for which the pivoted carriage is not suitable, it possesses features which make it desirable even for applications within the scope of the pivoted-carriage methods. Among these characteristics are: (1) Extreme simplicity of mechanical designs for various types; (2) Inherently high sensitivity obtained by not requiring the unbalance to vibrate the mass of a carriage; (3) Readings of unbalances for both correction planes made without mechanical changes; (4) Total insensitiveness to all building vibrations.

3. PRINCIPLES EMPLOYED IN NEW METHOD

In the new method the pivoted carriage is replaced by a simpler mounting and an electrical circuit or network. The functioning of this arrangement depends on the relation, which exists for almost any mounting, between the balance correction in one plane and the vibrations of any two given points of the rotor axis. The vibrations at two points on the axis are converted into two corresponding voltages by magnetic pick-ups (Fig. 1) similar to those employed for turbine blade and rotor vibration studies at the South Philadelphia Works of the Westinghouse Electric and Manufacturing Co. and described by R. P. Kroon in the June 1935 *Instruments*. These voltages are placed on the network in which the same relation obtains between them and a third voltage (produced by them in the network) as obtains between the vibrations at the two given points of the rotor axis and the unbalance correction in one balancing plane.

Thus this third voltage corresponds in both phase and amount to the unbalance effect at one correction plane; similarly, the third voltage of a second network corresponds to the unbalance effect at the other correction plane, the input voltages to this second network being the same as those of the first, namely the pick-up voltages.

The unbalance in one correction plane having been converted into a voltage proportional to the unbalance and in fixed phase relation with it, the problem becomes simply that of measuring the value of this voltage and its phase with respect to the rotation of the rotor:

a. *For quantity balancing of rotors,* the r.m.s. value of voltage is measured with an ordinary a-c. instrument calibrated in ounces of unbalance. The phase of the voltage, which corresponds to the position of unbalance correction, is indicated by having it time the flashing of a stroboscopic light, causing it to illuminate the rotor in that angular position in which the unbalance is opposite a stationary pointer. The angular position of the unbalance is recognized by means of numbers or other identification marks printed on the rotor.

b. *For balancing rotors in their own pedestals in the field* these voltage measurements are made by the use of a conventional a-c. potentiometer, or by the use of a commutator with angularly adjustable brushes on the rotor shaft in combination with a d-c. instrument. These methods of measurement take a little more time but do not require the use of thermionic tubes.[1]

[1]Methods of field balancing using measurements of phase and amount of motion at two points along the rotor axis together with vector calculations have been used by T. C. Rathbone ("Turbine Vibration and

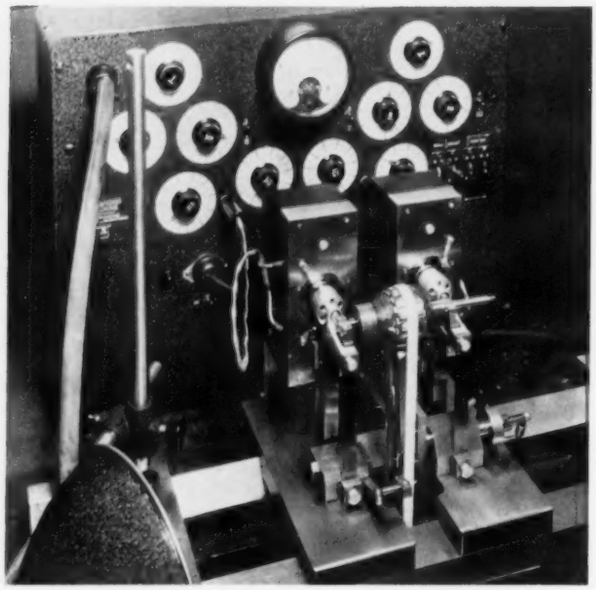

Fig. 3. Equipment for balancing small rotors. See also frontispiece opposite page 240.

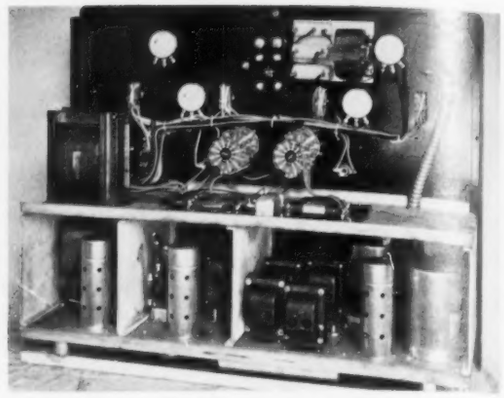

Fig. 4. Rear view of network cabinet.

4. DESCRIPTION OF TYPICAL APPARATUS FOR PRODUCTION BALANCING

At this writing (August 1935) the new method, though not commercialized, has already found successful embodiment in various forms of apparatus, all of which have been used with satisfactory results. The name "Electro-Network Balancer" has been proposed as a correct generic designation applying to any embodiment of the new method. Electro-network balancers may be classified according to purpose: (1) those permanently installed for quantity-production balancing and (2) those for field balancing. They may be classified also as to their method of use: (A) those which provide the bearings in which a rotor is to be balanced, and (B) those applicable to rotors in their own bearings. Still another classification is according to their applicability: (i) those for small rotors, say $1\frac{1}{4}''$ to $3''$ diam.; (ii) those for medium size rotors, say, up to 100 lbs., and (iii) those for very large rotors. There will now be described an electro-network balancer classifiable as 1-A-i. Much of this description applies to other types.

Fig. 1 is a schematic sketch showing the physical essentials (for one bearing) of the fundamental principle set forth in the preceding section. Fig. 2 is a perspective view of a rotor mounting and of the two magnetic pick-ups associated therewith, and clearly brings out all important features of design and construction. Each bearing pedestal and each pick-up is supported by a pair of parallel spring steel strips permitting oscillation along a horizontal line perpendicular to the rotor axis. Each bearing pedestal is so associated with its pick-up as to form a system having one degree of freedom in a horizontal plane common to both systems and to the rotor axis. Throughout the balancing of a production lot of rotors the distance between the two correction planes remains constant, as do also the masses set into vibration, the elastic moduli of the supports, the generative characteristics of the pick-ups, etc. In production work, all rotors of one lot are balanced at the same speed. Thus all factors contributing to the relation between the amount of unbalance in either plane and the resulting alternating e.m.f. are kept constant in the portions of the apparatus shown in Fig. 2. Floor vibrations have no effect on the calibration, by reason of the method of mounting. Striking with a heavy hammer the massive base seen in Figs. 2 and 3 does cause the mounting and pick-ups to oscillate, but these oscillations have no appreciable effect on the instrument readings unless they are of such great amplitude as to be clearly visible to the operator—who in such an event would naturally wait for them to die down.

The cabinet shown in Fig. 3 contains the network, the necessary power supply and control for the stroboscopic lamp shown in a reflector to the left, a circuit and an indicating instrument for measuring amount of unbalance, and switches necessary for convenient operation. There are three of these operation switches, as shown on the right of the cabinet panel. The double switch on the extreme right is an "end switch" which selects one of the other of the two networks for operation. Thus with the switch at the "right end" position the indications (instrument and stroboscope) apply to the right end correction plane; with the switch at the "left end" position the indications apply to the left end. The center switch is an "angle-amount switch" which places the output of whichever network is chosen by the "end switch" either into the a-c. instrument circuit or into the stroboscopic lamp circuit. To the left of the group is the "sensitivity switch" with which either of two indicator scales of different sensitivities can be chosen.

The dials shown on the cabinet are for use in adjusting and calibrating the balancer for a particular type of rotor. They will be described more fully later.

The rotors are rotated by a belt and a motor as shown in Fig. 3. For facility in placing and removing rotors a belt lifter mechanism is provided, shown in the lifted position in Fig. 5.

5. PROCEDURE IN PRODUCTION BALANCING

With the balancer adjusted for the particular type of rotor the complete unbalance indication is obtained as follows (referring to Fig. 3; the switches mentioned are those of the group of three at the right side of the panel):

1. Press foot pedal to rotate rotor.
2. Place "end switch" at "left end" position.
3. Place "amount-angle switch" at "amount" position and read amount of unbalance at left end correction plane on instrument.

Balancing," *Mechanical Engineering*, October 1929), and by E. L. Thearle ("Dynamic Balancing of Rotating Machinery in the Field," *Mechanical Engineering*, October 1934). A commutator of the cam and a contactor type is used for measuring phase and amount of an a-c. voltage involved in field balancing by E. L. Thearle. A pivoted carriage type of balancing machine using the commutator method for measuring the phase and amount of an a-c. voltage was exhibited at the Century of Progress, 1933, by The Tinius Olsen Co.

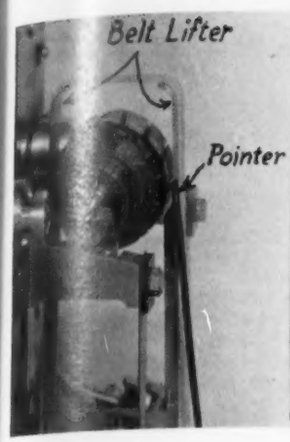

Fig. 5

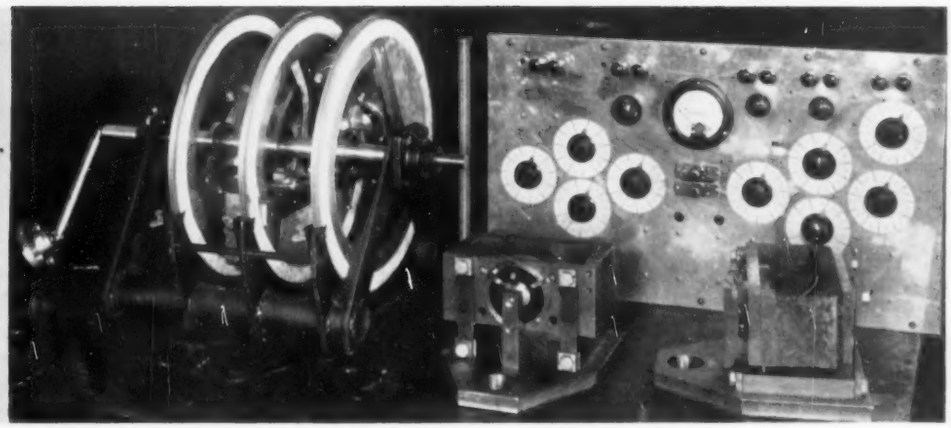

Fig. 6. Equipment for field balancing of large rotors. At left, source of emf's.

4. Place "amount-angle switch" on "angle" and read the position of unbalance opposite pointer with stroboscopic light.
5. Place "end switch" at "right end" and repeat amount and angle readings, using appropriate position of the "amount angle switch."
6. Release foot pedal to stop rotor.
7. Press belt lifter lever and remove rotor. The sensitivity switch changes the sensitivity of the indicating instrument: for small unbalance this switch is placed in the "small" position and for large unbalance in the "large" position.

6. PROCEDURE FOR NEW ROTOR

The network constants, as set with the middle elevation dials shown in Fig. 3, depend only on the weight distribution of the rotor to be balanced. Therefore a given rotor design will always have the same network constants, *i.e.*, the same dial settings. With a rotor for which the dial settings of the production type apparatus are unknown, they may be found with the following procedure:

1. Balance the rotor by means of indications made with dial settings for any rotor. This operation requires a longer time than with the correct dial settings in that repeat runs are usually necessary (due to the inaccuracies introduced by incorrect dial settings) after the corrections as indicated are carried out.
2. With the balanced rotor an unbalance is placed in the left end correction plane and the "end switch" (see above description of Figs. 2 and 3) placed on "right end" position. With the correct dial settings and only the correct dial settings the instrument reads zero, since there is no unbalance in the right end. If the instrument does not read zero the two network adjusting dials are moved until it does.
3. In a similar way the network for the left end is adjusted, *i.e.*, with the "end switch" placed on "left end" and with an unbalance only in the right end. After the network dials are adjusted the dials at highest elevation (meter dials) are adjusted to give the correct instrument reading for known unbalances in the two balancing planes.

The remaining four dial settings (two dials corresponding to each network) depend on the speed at which the rotor is to be rotated for balancing.

To set the dials for the field type of electro-network balancer (applied to the balancing of rotors in their own pedestals in the field) a perfectly balanced rotor is simulated in the network by compensating for the initial voltages in the pick-ups due to the initial unbalance of the rotor. This is accomplished simply by applying the well-known a-c. potentiometric method: opposing voltages by other voltages of equal frequency, form, phase and value. The source of these standard voltages is the simple arrangement shown in Fig. 6, comprising a camshaft driven synchronously with the rotor, bearing three cams with each of which there is associated a magnetic pick-up whose phase is adjusted by one of the three large graduated rings seen in Fig. 6. Otherwise, the procedure is the same as for the production type equipment.

7. CHARACTERISTICS IN DETAIL

(*A*) *Sensitivity and Accuracy*—A minimum unbalance of an amount sufficient to cause the bearing pedestals to vibrate at 0.00005″ amplitude can be indicated. This is of the order of 0.001 ounce inch unbalance at one correction plane of a 2″ diameter motor rotor. The accuracy of unbalance indication for unbalances of the order of 0.05 ounce inch in a 2″ diameter motor rotor is within 3% error.

(*B*) *Summary of Features Contributing of Speed of Indications*—(1) No driving motor speed adjustments required. (2) Readings for both unbalance corrections made in a single run without stopping rotor. (3) Adjustments for each rotor are not necessary before taking readings. (4) The readings are direct in convenient units. Curves or calibration charts are not required. (5) Errors of indication have been reduced to the point where a single run is usually all that is required. (6) The machine is not hindered by building or floor vibrations. (7) Changes in set-up from one type or rotor to another can be quickly made, provided the dial settings for the new type are known.

(*C*) *Limitations of New Balancer*—(1) The vacuum tubes used may have to be replaced at the usual intervals of 1000 hours' service. (2) Balancing at speeds below about 900 r.p.m. is impracticable. (3) The determination of dial settings is not as obvious a procedure as that of resetting a pivot carriage type of balancing machine.

8. "AUTOMATIC BALANCING"

The amount of unbalance in each plane being automatically indicated, and its angular position being automatically located, it will no doubt occur to *Instruments* readers that there are thus furnished the "starting data" of a typical problem in "complete instrumentation." The designers have not been unmindful of the possibilities of having the equipment described control emery wheels, etc., for subtracting weight in correct amounts and at correct locations—all automatically. They have done some experimenting along this line. They are chiefly engaged, however, in perfecting the several distinct types of unbalance *measuring* equipment, upon the conclusion of which work it will then be proper to develop types of unbalance *correcting* automata.

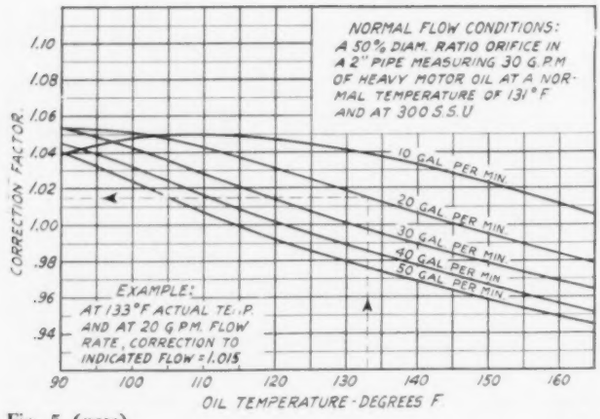

Fig. 5 (new)

Orifice Coefficients

AUTHORS' CLOSURE

THE authors feel highly honored at the interest manifested by the several discussers of their article and hereby express their appreciation of the many ideas thus contributed to a subject which doubtless will increase in importance as industry recognizes the need of accurate measurement of liquids of high viscosity.

In particular are they appreciative of Ed S. Smith, Jr.'s splendid development of the empirical formulae which can be used to express the same data. While proper use of these formulae undoubtedly depends somewhat upon the proper choice of operators, a little experience will soon demonstrate that they are valuable tools to use in the correlation of different sets of experimental data on one common basis. They can also well be used for ready interpolation, especially for building tables for everyday use in commercial design work. The essential differences between the authors' Fig. 5 (a correct copy of which is reproduced herewith as a direct comparison with Ed S. Smith's Fig. 5A) is that Fig. 5 is based upon *actual* flow rates and with the use of an *ordinary manometer* or *standard measuring device*, whereas Ed S. Smith's Fig. 5A is based upon the *indicated* rate as shown by a meter having a *specially shaped cam or bell* which compensates for the variation of the coefficient from a flat line throughout the range of the meter. It was the authors' intention in this article to confine the text to the characteristics of the orifice itself in the measurement of viscous flow, and not to bring into consideration any means of mechanically compensating for some of the variables encountered in viscous flow measurement. It is, of course, evident that such mechanical means can be, and in fact are, used in commercial meters as described by Ed S. Smith and shown by his Fig. 5A, in order to minimize the corrections for viscosity, density and flow rate. The basic corrections without readjustment are, however, as shown in the authors' Fig. 5. Nevertheless, the authors are inclined to agree with Ed S. Smith that such combined correction curves are generally not safe to use and that for commercial use it is better to use separate curves for each variable.

In all sincerity the authors disclaim any intention of inferring they were the first to establish the variation of orifice coefficients with Reynolds numbers. So much has been written in preceding literature on the subject of variation of orifice coefficient with Reynolds number for turbulent flow that any such claim would have been entirely out of line. The intent of the brief discussion of the Reynolds number as an operator was to attempt to clear up any misunderstanding as to the true value and usefulness of the Reynolds number as a criterion and to discuss it in a straightforward and sincere manner, bringing out both its good and its weak points.

Prof. Carson's objection to the type of orifice flange shown in Fig. 2 can readily be overcome and actually is so accomplished in actual practice by putting a seal weld at the junction of the flanges and the pipe wall which will effectively prevent any leakage around the threads. As a matter of fact, the filler type of design mentioned by Carson was actually used in these experiments, the filler being doweled to each pipe line flange so that a smooth continuous inside pipe surface was obtained from pipe line to filler.

The oil flowing through the system was the indicating fluid in the manometers, thus making the simplest type of calibration medium because of the elimination of separating chambers and other special apparatus, as well as of corrections

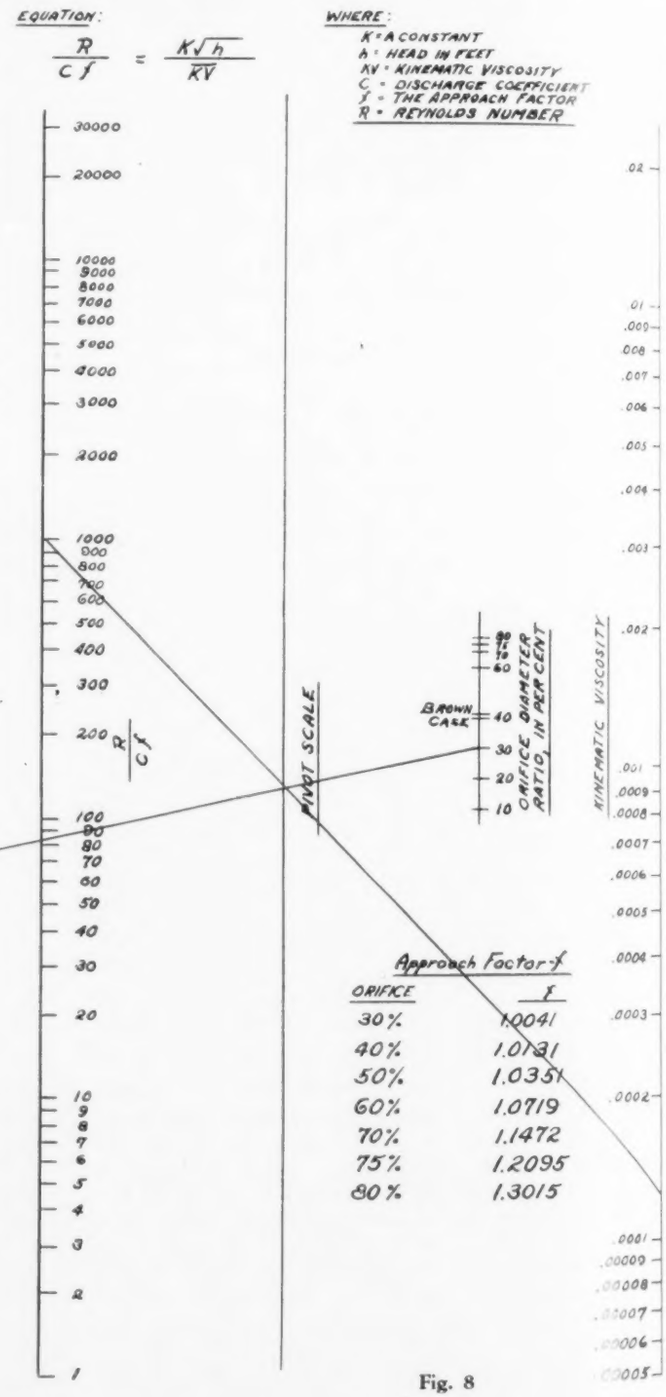

Fig. 8

for Viscous Liquids

By G. L. TUVE and R. E. SPRENKLE

In our November 1933 issue (pages 201-206) we published the original article on orifice coefficients for viscous liquids, representing three years of research by G. L. Tuve, Associate Professor of Mechanical Engineering, Case School of Applied Science, and R. E. Sprenkle, Mechanical Engineer, Bailey Meter Co.

Discussions by Ed. S. Smith, Jr., by W. H. Carson and H. J. Evans, by Ronald B. Smith, by C. E. Lucke and by Edgar Buckingham appeared in our August 1935 issue, pages 202-205, 225.

for zero level, density and so on. The cut-and-try method of determining coefficients objected to by Carson can largely be eliminated by the use of a nomogram or alignment chart, a typical one of which was developed by V. T. Kartorie of the Case School of Applied Science for use in these tests and reproduced herewith as Fig. 8. As an example of its use, it is desired to use a 30% diameter ratio orifice to produce a head of 0.2 ft. of oil having a kinematic viscosity of 0.000123. The intersection on the pivot scale of a straight line drawn between the orifice size and maximum head furnishes a point through which to draw a straight line from the kinematic viscosity scale to the scale expressing Reynolds number divided by the product of the coefficient and the approach factor. In this particular example this value becomes 1000. Although a small amount of cut-and-try is necessary in order to obtain the correct coefficient and Reynolds number from this expression, it can easily be done from Fig. 3 of the article.

It was not intended to recommend straightening vanes in commercial installations unless the piping arrangements preceding the orifice were such as to need them. No data are available to our knowledge which show that viscous flow coefficients differ with and without the use of straightening vanes, when the straight pipe preceding the orifice is of sufficient length to eliminate any disturbances set up by bends or combinations thereof.

Carson points out that the orifice thickness should be a definite percentage of pipe diameter. This is true; further, this thickness should be proportional to the orifice diameter, as well as to the height of the orifice edge above the pipe surface, otherwise called the orifice rim. For turbulent flow, the following specifications have been established by the Joint A.G.A.-A.S.M.E. Orifice Committee:

Thickness of the orifice plate at the orifice edge shall not exceed
(a) 1/50 of the pipe diameter,
(b) 1/8 of the orifice diameter,
(c) 1/4 of the orifice run.

In the absence of any data to the contrary, the same limitations could be applied as well to the measurement of viscous flow.

Ronald B. Smith quite justly calls attention to possible errors due to flexing the orifice plate under stress. Undoubtedly this matter would be of serious importance if the differential pressures across the orifice plate were in excess of 4 or 5 lbs./in.², especially if these plates were of pliable material such as brass. In the experiments recorded in this paper, however, the differential pressures never exceeded 2½ or 3 lbs./in.² All but one orifice were of monel which is a much stiffer material than brass. In fact, the first year's experiments were all made with differentials ranging from 6" to 35"; and later, after the apparatus had been revamped to obtain larger differentials, no perceptible difference between the data from the two series of tests could be noted. If plate deflection took place when operating at the higher differentials, it was of such small extent as could not be noted with the apparatus used in these tests.

The authors are indebted to Dr. Lucke for his suggestion regarding the placing of all the test data on a flow resistance basis, similar to that used in presenting friction flow data for pipe lines. Such plotting would then show the upper and lower critical values of the Reynolds number, which would make interesting comparisons with pipe line data when placed on Reynolds number basis.

Typical graphs of this type are shown in Fig. 9 for the 30%, 50% and 80% diameter ratio orifices used in these tests, all plotted on the basis of the flow resistance coefficient against Reynolds number. There will be noted a distinct overlapping of these resistance curves between Reynolds numbers of 200 to 1000 for the 30% ratio, and between 1000 and 2000 for the 50% ratio. These limits are the critical Reynolds number ranges for these respective diameter ratio orifices. For the 80% diameter ratio orifice the resistance curves are less well defined, particularly in the range of critical Reynolds numbers. This may be due partly to lack of complete data but mostly it is believed, to the great difficulty of obtaining satisfactory calibration data for, and the consequent lack of stability of, an orifice of this diameter ratio size.

At first glance, it might seem that the non-continuity of these resistance curves through the upper and lower critical Reynolds numbers would cast an element of doubt on the accuracy of the orifice discharge coefficient curves shown in Figs. 3 and 6 of the article, which are continuous throughout the entire range of Reynolds numbers. However, as Kretzschmer brings out[1], a decrease in the Reynolds number through the critical range increases the contraction coefficient from approx-

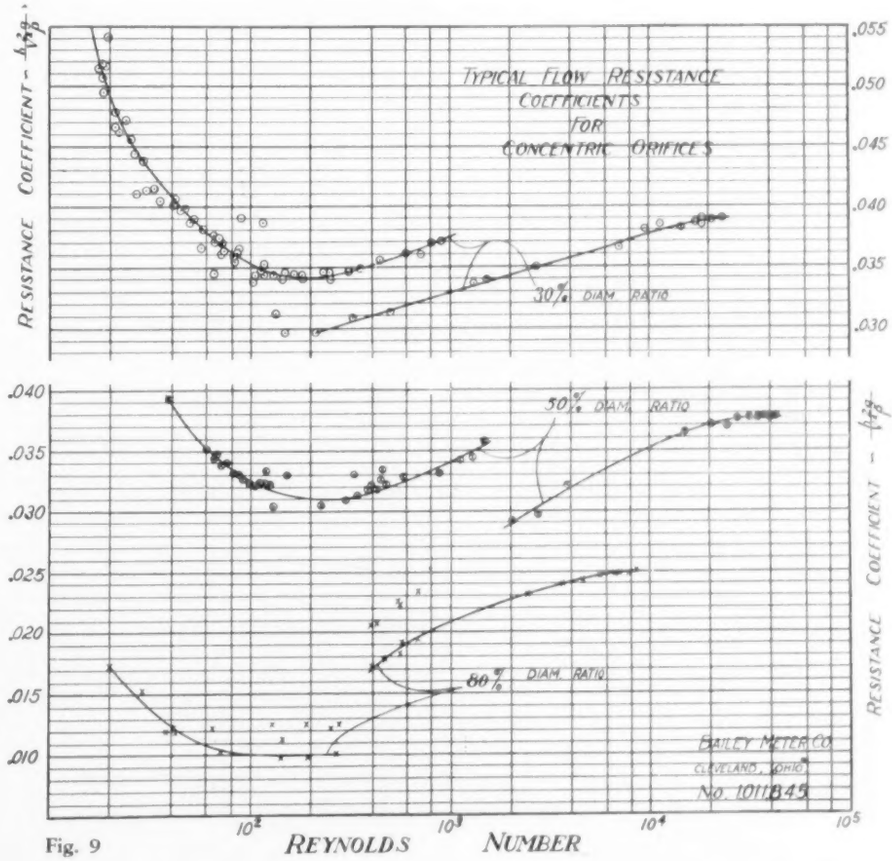

Fig. 9

imately 0.6 to a value approaching 1.00. This change in contraction coefficient is so great (being nearly 66%) that it alone determines the value of the discharge coefficient and *suppresses the effect of the flow resistance coefficient.* This allows the orifice coefficient to increase until it approaches a value of 1.00 for the high diameter ratio orifices where the contraction coefficient is nearly 1.00, whereupon the orifice performance approximates that of a flow nozzle, with the discharge coefficient decreasing with decreasing Reynolds numbers.

This theory is borne out by the works of all other experimenters in determining orifice and flow nozzle characteristics through low Reynolds numbers. So long as their results were plotted on the basis of orifice discharge coefficient *vs.* Reynolds number, smooth continuous curves were obtained from the lowest to the highest values of Reynolds numbers, regardless of the break in the resistance curves through the critical range. This is fortunate as it enables the designer and user of orifices for commercial metering of various fluids to use with certainty the coefficients of discharge for the diameter ratio size orifice required.

In answer to Dr. Lucke's query as to what precautions were taken against air entrainment, two steps were taken. First, the air was worked out of the line and manometers by recirculating the fluid, and by squeezing the connecting tubing to the manometers. Then vents before and after the orifice were kept open during the tests. Naturally, any possible entrainment in the fluid passing through the orifice could not have been detected, unless a glass pipe had been used preceding and following the orifice. Such pipes were not available at that time, but would doubtless be of considerable value in future tests so as to show the flow through the orifice visually. A further elaboration would consist of making microphotographs of the flow under a beam of intense light, using a lightly colored oil so as to improve the visibility.

As a matter of record, since several contributors have brought out the point, all data in this article were based on the Reynolds number determined from the size of the orifice hole d and the velocity through the orifice. To correct from the Reynolds number as based on the pipe line diameter D instead of the orifice, the following formulae obtain:

$$R_d = \frac{D}{d} R_D \text{ or } R_D = \frac{d}{D} R_d$$

where R_d = Reynolds number based on orifice diameter and velocity.

R_D = Reynolds number based on pipe diameter and velocity.

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[1]Kretzchmer. (The Effect of Friction on the Discharge Coefficient of Nozzles and Orifices.) *V.D.I. Forschung,* Vol. 4, 1933, page 93.

INSTRUMENTS' BOOK SHELF

Heat. By James M. Cork. John Wiley & Sons, New York, 1933. Cloth, 6x9¼ inches, xii + 279 pages. Price $3.00.

Primarily designed for use as a students' text (as evidenced by "Questions and Problems" at chapter ends) this work should find also a prominent place on the shelf of the research man employed by any industry built upon thermal processes. Which is to say that nearly every research laboratory where *Instruments* is read will find Prof. Cork's latest book a valuable reference. Nearly every *Instruments* subscriber will be interested in Chapter I, "The Measurement of Temperature," and in numerous descriptions of apparatus scattered throughout the ten other chapters. Some of these devices were designed by the author himself. They are described briefly, having been reported in detail in the *Journal of the Optical Society of America* and in the *Review of Scientific Instruments.*

But this compilation is much more than a set of descriptions of experiments. In fact, Prof. Cork has (wisely!) devoted little space to the "classical" experiments — which are getting to be "historical" nowadays, because Plank's work on radiation, Einstein's and Debye's on specific heat, Bragg's on expansion and Langmuir's on evaporation seem to be what the new generation of university students and research men want to acquaint themselves with.

The topical arrangement, though not progressive and hence requiring that the reader be an advanced student, is nevertheless orderly. The initial chapter (temperature measurement—a mixture of classical and modern) is followed by one on specific heats and one on thermal expansion, in both of which the student is led to the newest theories. Then come: IV. Heat transfer by conduction and convection; V. First Law of thermodynamics; VI. Radiation; VII. Change of state and VIII. Continuity of state. The ninth, an introduction to thermodynamics, makes a good little text by itself. Last come two useful reference sources: X. Production of low temperatures and XI. Production of high temperatures—each brief but fairly comprehensive. Thirteen appendices of useful data, a name index and a subject index (the latter a poor job) complete the volume.

M. F. Béhar (2.06)-B-

Photoelectric and Selenium Cells. By T. J. Fielding. Instruments Publishing Co., Pittsburgh, 1935. Cloth, 5⅛x8⅛ inches, 146 pages. Price $1.75 postage prepaid.

This new book fills a hitherto unoccupied place in the literature on light-sensitive phenomena. It places in the hands of those who do not care for a mathematical treatise the fundamentals of theory, apparatus, and uses of light sensitive devices. While the text is so written and illustrated that it is not beyond a high-school student, it is sufficiently complete to meet the needs of the engineer or scientifically interested reader who wishes an introductory discussion of the art and practice.

The history and basic principles of light sensitivity of emissive, conductive, and voltaic types is covered in a concise and interesting manner. A chapter on making of selenium cells gives directions which can be successfully carried out by workers whose equipment is limited. This information is not found in most texts on photoelectric cells and is of real value to experimenters. Amplifier circuits are described in detail with suggestions for a wide variety of home experiments. These experiments give a good general view of the place of light-sensitive devices when coupled with the explanations and illustrations of present industrial uses. Television, talking pictures, noctovision, safety devices, counting, inspection, precision gaging, burglar alarms, smoke detectors, smoke density control and many other actual uses are explained.

The outline of potential adaptations of photo-electric devices is sufficient to stir the imagination of an interested reader to further study of these newcomers in industrial controls.

Arthur L. Riche (5.3)-B-

Marketing Industrial Equipment. By Bernard Lester. McGraw-Hill Book Co., Inc., New York, 1935. Cloth, 6x9 inches, x + 307 pages. Price $3.50.

In the last two or three years many publishers and editors of technical journals have begun to print articles on economics, business administration and other topics which, before the depression, interested only the industrial executive—not the industrial technician. The latter, it appears, has begun to realize that his future depends largely on his learning the ropes. If he is wise, he wastes little time on controversial subjects which, being political footballs, are in a state of flux; and concentrates his attention first of all on those subjects pertaining to the distribution of the tangible products which he designs or manufactures. *Instruments* readers belonging to this class of wide-awake technicians, we have been mindful of our obligation to them, but heretofore have not found the opportunity. The appearance of Lester's book, however, does provide the opportunity: the least we can do is to bring it to our subscribers' attention. It is "the first book devoted to a comprehensive study of the problems involved in distributing machinery and equipment from the manufacturer to the ultimate user." This statement (the jacket blurb) sounds like an exaggeration but is accurate: in order to survey as wide a range of subjects as included in the scope of this work, one would have to wade through the last twelve annual *Proceedings of the National Industrial Advertisers' Association,* through numerous back issues of the old *Class* and of *Class and Industrial Marketing,* through selected articles in general advertising and general business periodicals, and even through a stack of selected government reports and pamphlets.

The author remarks in his preface that although productive machinery is well designed and manufactured, and well used to produce goods in quantity at low cost, "we have not learned how to distribute this machinery in an economical manner. This problem is still unsolved—largely because the engineering mind, absorbed in the technical details of the machine itself, is frequently not adapted to solving problems of a commercial character." Therefore, in spite of the fact that his book "is intended to assist those who are . . . engaged in . . . distribution . . . as well as students in technical and business schools," we recommend it to engineers, research workers and production men whose normal duties lie entirely outside of their companies' sales promotion activities.

M. F. Béhar (12)-B-

Foremanship Development. Published by Industrial Relation Department, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa., 1935. Paper, 8½x11 inches, 60 pages. Price $1.00.

The importance of supervisory forces in the present-day industrial organization emphasizes the need for the adequate and simplified plan for the training of foremen and other supervisors, contained in this little manual which is based upon the experience of the Westinghouse Electric and allied companies, and that of others who have been active in supervisory training. It is intended for both group leaders and the members of conference groups.

Part 2, Section 1 of this course briefly presents the increasingly important place which the foreman and the supervisor hold in industrial organization. Then follows a series of practical suggestions for conference leaders, including underlying fundamentals, suggested methods, conference technique, self evaluation for leaders, a working library, etc. The final section outlines a series of 38 conferences on major problems in foremanship, including outlines for discussion on collective bargaining, foremen as managers, as leaders, labor turnover, waste, developing understudies, company policies, wages, cooperation, self analysis, and similar topics.

(12)-B-

Telemetering and Totalizing*

By PERRY A. BORDEN and M. F. BEHAR
Member A.I.E.E. Editor, *Instruments*

(*Continued*)

5. Current Class.

(a) Principle and Characteristics.

As its name indicates, this class of systems is that in which the transmitted electric variable is a current (usually direct current). The value of this transmitted current is a function of the measured magnitude: in some early systems[1] it was an inverse relation but present-day practice favors direct proportionality. (In systems designed for totalizing the relation must of course be strictly linear.)

When the original measurement has to be made with a relatively delicate instrument, the use of contacts or electron tubes is necessary; whereas when the primary element is, say, a large float-and-pulley device, the transmitter associated therewith may take the simplest form of variable resistor. Similarly, the transmitter proper takes many different forms in practice but it generally falls into one of two groups: (1) those designed to be associated with relatively delicate primary measuring elements such as millivoltmeters, and (2) those suited for use with relatively powerful primary measuring elements such as valve-position indicators. Therefore, the number of ways in which primary and transmitting elements may be combined into serviceable transmitting sections is limited.

Current-class systems having transmitting sections wherein the torque produced by the measured magnitude is actually opposed and balanced by the reaction in an electrical movement are particularly suited to the telemetering of electrical magnitudes. Systems wherein a spring is interposed between the deflecting element and the relay contacts, or where a "follow-up" device is used, are particularly suited to position indicating and to applications such as pressure, liquid level, etc., where the deflection of the primary element is attended with considerable force.

In a transmitting section of the relay type, the torque or deflection of the primary measuring element is matched by that of an element of the ammeter type (usually permanent-magnet moving-coil). Any deflection of the primary measuring element causes the relay mechanism to adjust a current flowing in the circuit of the opposing element, and the result is that there flows in this circuit a current representative of the measured magnitude. The relay system may embody definite contacts directly controlling the current through the agency of a motor-operated rheostat, or electron tubes may be used, thus greatly reducing the work of the contacts. The interconnecting line and receiving instrument are included in series with the circuit of the opposing element; and, since the relay device keeps the current proportional to the torque developed in the measuring element, circuit resistance does not affect the performance so long as sufficient voltage is available to force current of the desired value through the resistance.

Totalizing. So long as linear relationship is maintained between the current and the measured magnitude, totalization may be accomplished by placing a number of independent transmitters in parallel and measuring their joint output on a single receiver. It is to be noted, however, that as the transmitted current increases the line voltage must rise, so that in totalizing a number of circuits through a single transmitting line there is a limit to the system capacity, namely, the maximum voltage which the transmitters can supply. It will also be apparent that individual transmitters feeding into a common line will tend

[1] J. J. Linebaugh. Power-Limiting & Indicating System of the C.M. & St. P. Ry. *General Electric Review*, Vol. 23, April 1920, pages 292-306.

*Sixteenth chapter (XLIV) of Part Seven (Handbook of Industrial Electrical Measurements and Control) of Béhar's *Manual of Instrumentation*. See editorial announcement of this series on page A7 of November 1933 *Instruments*. Each chapter is subjected to a final revision shortly before its appearance in this serial form, in order to assure that the subject matter is thoroughly up-to-date. This new book is not published serially in any other periodical. Entire contents copyright. To be issued in book form on or about Jan. 1, 1936.

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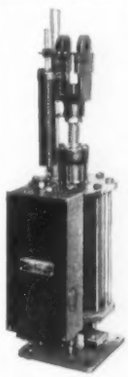
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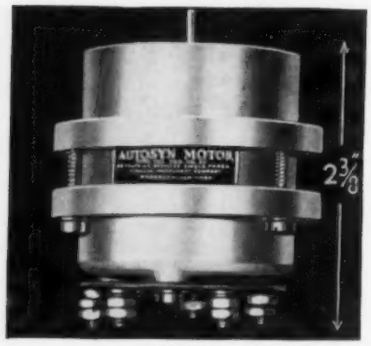

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to react on one another in the sense that if one unit changes its setting to meet a changed value of the measured magnitude, the new value of current flowing in the line will develop a new value of electromotive force in the nature of line drop. This will react upon other transmitters in the system so that, even though their measured magnitudes may not be subject to variation, their relay mechanisms will have to adjust themselves to supply current into a circuit whose equivalent resistance has changed. Manufacturers of current systems of telemetering have thus found it necessary to provide against "pumping" where two or more transmitters feed into a common line.

Receivers. Ammeter type receiving instruments are generally used, and of course a number of them may be placed in series on a single circuit without affecting one another's indications. This is a distinct advantage. The current transmitted over long lines (or over communication circuits) is usually in the order of milliamperes, so that in practice the receivers are as a rule milliammeters. Alternatively, a potentiometer may be used to measure the transmitted current in terms of potential drop across a standard resistor.

Theoretically, current systems of telemetering may be used for integrating, the receiver then being an ampere-hour meter, but in practice it would require the use of a milliampere-hour meter—not a commercially practicable form of meter—and therefore current systems when used for industrial remote integration are modified to permit the use of meters resembling ordinary watthour meters.

(b) Typical General-purpose Current Systems

Westinghouse Current Systems.

In the original current-balance system introduced by the Westinghouse Co. an electrical measurement is performed by a Kelvin balance type of movement such as is employed in that company's relay-type recorder (see *Instruments*, Jan. 1935). This element may be a voltmeter, an ammeter or a wattmeter. In any case its torque is directly opposed by that of a d'Arsonval movement acting upon the same deflecting member. The schematic diagram, Fig. 44-1, brings out the principles employed. In Fig. 44-2, which shows

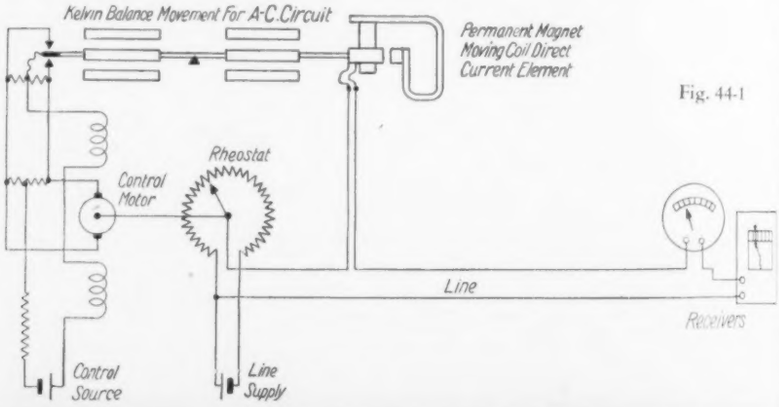

Fig. 44-1

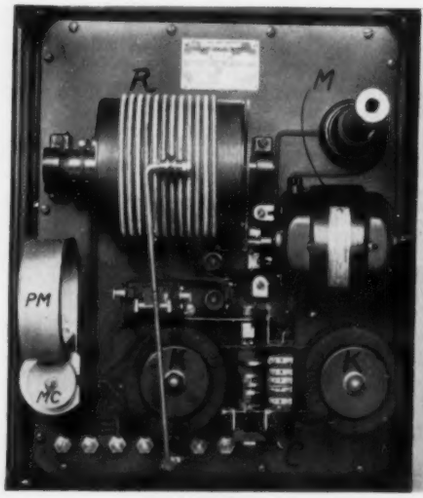

Fig. 44-2

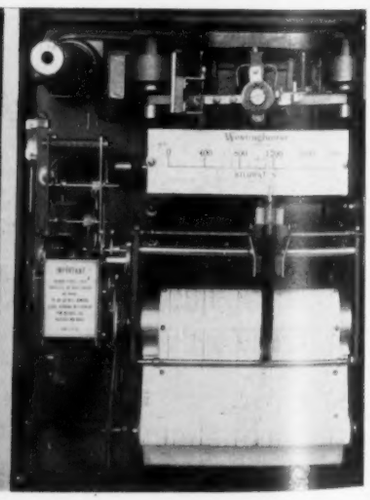

Fig. 44-3

the transmitting section, may be seen the coils K-K of the Kelvin balance which develops a torque representative of the volts, amperes or watts under measurement. The transmitted direct current passes through a d'Arsonval element (of which *PM* is the permanent magnet) which acts to oppose the torque of the Kelvin balance. When the elements are out of balance the contacts C start the reversing motor M, adjusting the rheostat *R* and thereby increasing or decreasing the current in the d'Arsonval element in a sense to restore balance. The receiving instrument (Fig. 44-3), which is supplied with this current through the transmitting line, is a recording d-c. milliammeter with its scale graduated in the units measured at the transmitting section.

In a more recent development of the Westinghouse current-balance telemetering system an electronic relay is employed, which eliminates the motor-driven rheostat essential to the earlier form and also renders unnecessary an auxiliary source of d-c. supply.

The Westinghouse "Pilotel" relay-type recorder (see *Instruments*, Feb. 1935, page 42) is readily applied to telemetering: The torque of the measuring instrument is balanced by that of a d'Arsonval element fed from a vacuum tube circuit controlled in turn by a variable inductance coupler responsive to unbalance of torque between the elements. The resultant d-c. is transmitted to the distant point, where it is indicated or recorded by instruments of the milliammeter type.

The Westinghouse "Rectox" system of telemetering is a simplified method wherein the output of special current or voltage transformers is rectified, filtered and sent over a communication circuit. It provides a relatively inexpensive method of transmitting current or voltage measurements.

General Electric Current System.

The General Electric Co.'s "Torque-balance" telemetering system embodies in its transmitting section (Fig. 44-4 and -5) a measuring element and a restraining element coupled to a common shaft which also carries a mirror. This mirror, as in the G.E. Photoelectric Recorder (*Instruments*, Feb. 1935, page 41) governs the distribution of light between two photocells. The moving part has no control springs, the total force opposing the measuring torque being derived from the current which passes through the restraining element. This current is transmitted through the connecting line and operates a receiving instrument of the milliammeter type.

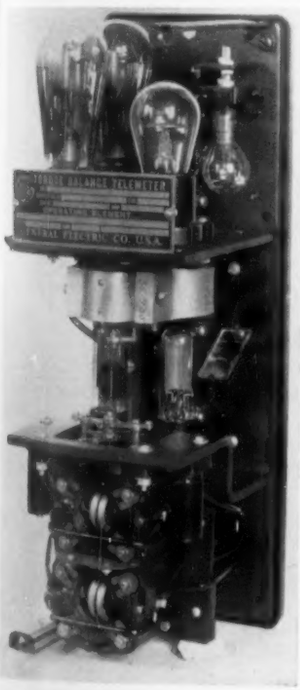

Fig. 44-4

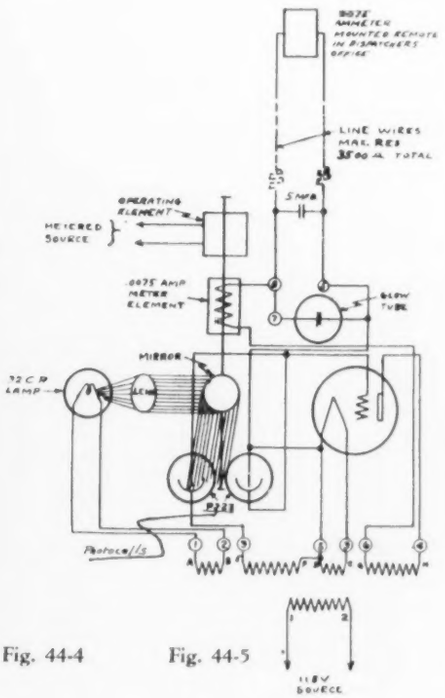

Fig. 44-5

G.E. Rectified-current type.

For the transmitting of voltage and current measurements, the General Electric Co. furnishes a system in which the secondary current of a special voltage or current transformer is rectified in a full-wave rectifier tube and the

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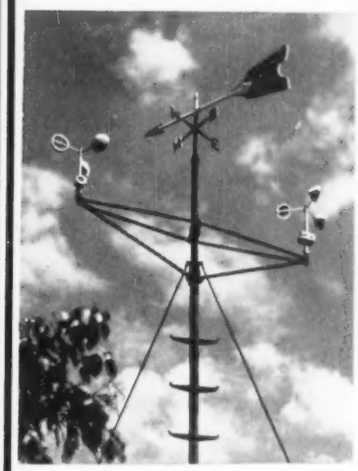

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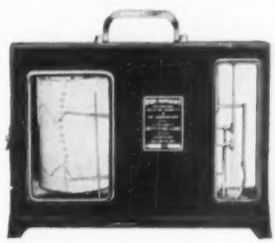

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d-c. output transmitted to the receiving point, where it is measured in a standard milliammeter type of movement. The system is so designed that the rectifier delivers approximately 25 milliamperes at full voltage or current, as the case may be, in the instrument transformer.

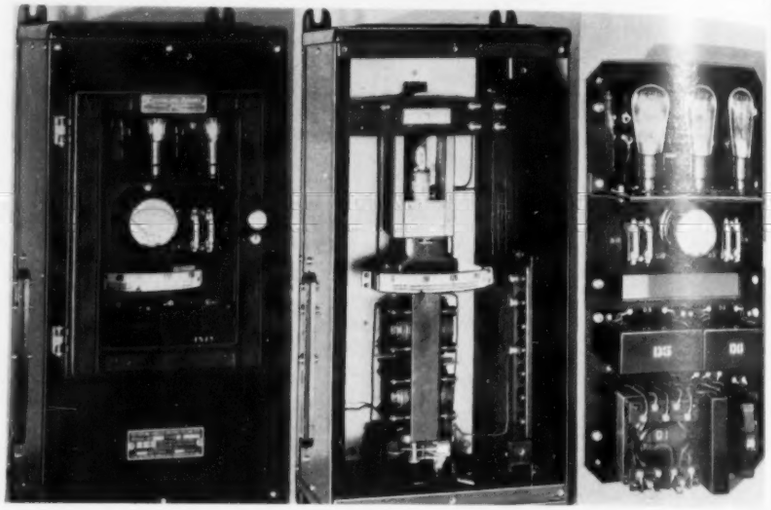

Fig. 44-6. *Left*—**Complete Esterline-Angus transmitting unit.** *Center*—**Primary measuring element and d'Arsonval transmitting element.** *Right*—**Removable front panel carrying the auxiliaries.**

Esterline-Angus System.

In the Esterline-Angus Co.'s telemetering equipment, provision is made for incorporating in the transmitting section any one of a variety of measuring units (made by that company or by others). The transmitting section is shown in Fig. 44-6 and its internal diagram in Fig. 44-7. The primary measuring element is shown at *D*-12, and immediately above it a d'Arsonval element *D*-11, carrying a contact *D*-20 which floats between two contacts on the deflecting member of the primary element. The output of a 400-volt winding on the transformer *D*-1 is rectified by two three-element vacuum tubes *D*-2

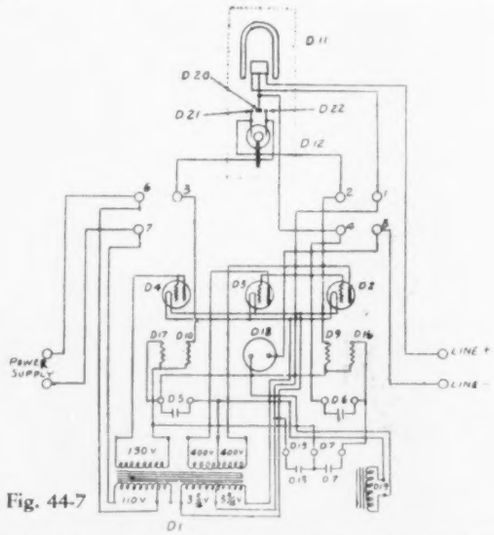

Fig. 44-7

and *D*-3, the rectified current passing through the d'Arsonval movement *D*-11, and through the line to the receiving instrument, completing its circuit through the milliammeter *D*-18. As the reading of the primary measuring unit varies, the contact *D*-20 engages one or the other of the contacts *D*-21 or *D*-22, either lowering or increasing the grid voltage, and correspondingly varying the plate current through the d'Arsonval element *D*-11 until a state of equilibrium is restored and the contacts opened. Since there is no mechanical connection between the measuring element and the d'Arsonval movement the transmitter constitutes a true "follow-up" mechanism and is equally suited for transmitting measurements derived from high-torque and low-torque movements.

Midworth Repeater.

As an example of British practice in telemetering may be mentioned Midworth's "Distant Repeater" produced by Evershed & Vignoles and marketed in this country by the James G. Biddle Co. This is a telemetering system of the current class, embodying a contactor type of primary- and transmitting-element follow-up and having the value of its transmitted current controlled by a motor-operated rheostat. The operating principle will be understood by reference to the schematic diagram, Fig. 44-8. This system finds a wide application not only in the telemetering of electrical measurements but in the transmission of liquid level measurements and in general position indication. It also is used in remote control and is regularly supplied in a form suited to the steering of ships.[2]

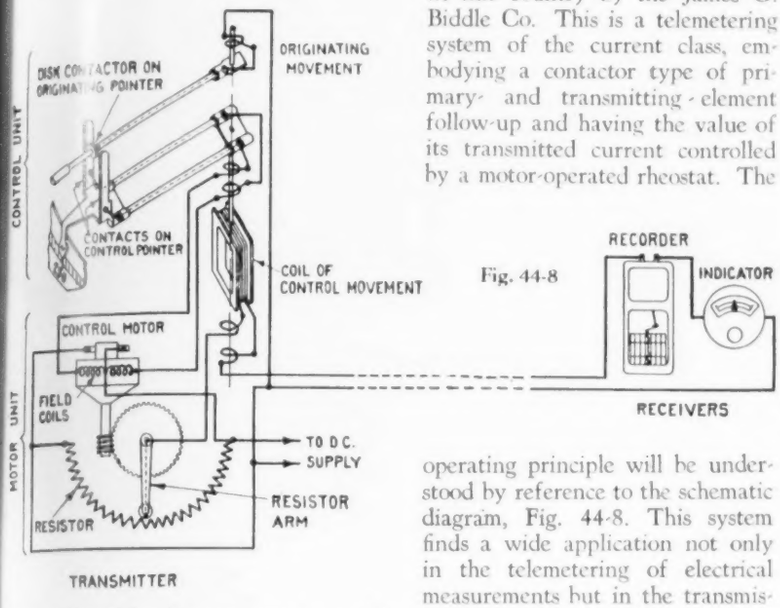

Fig. 44-8

(c) Volt-ampere Telemetering System.

An amplification of the current balance principle, applied in the remote measurement of volt-amperes,[3] employs at the point of measurement two transmitting elements, one connected to measure active-, and the other reactive-component of the load. Each of these transmitters controls a current proportional to the measured magnitude. A third unit, also located at the sending station, combines these two currents in a Kelvin balance element comprising two electrodynamic members on a common deflecting part, thus developing a torque proportional to the sum of the squares of these two currents, *i.e.*, to the sum of the squares of the measured magnitudes. This torque is opposed by that of an electrodynamic element on the same deflecting part. The current flowing through this electrodynamic element is the remotely transmitted current, and it is automatically adjusted to effect a balance. Since the balancing force is proportional to the square of this transmitted current, and since the torque so opposed is proportional to the sum of the squares of the measured magnitudes, the transmitted current is proportional to the square root of the sum of the squares of the active and reactive components: to the *volt-amperes* of the load. This system is capable of wide modification for the carrying out of a large variety of mathematical processes.[4]

A volt-ampere telemetering system as described above is commercially produced by Westinghouse.

(d) Flow Meters Using the Current Principle

A widely used method of measuring the rate of flow of fluid is to install in the pipe line an orifice or other device producing a differential head, and to connect the upstream (high-pressure) and downstream (low-pressure) sides to a manometer in order to measure the differential h, using the well-known relation $Q = C\sqrt{2gh}$ to calibrate the manometer in terms of fluid quantity-rate Q. A mercury manometer with a float in one of its two chambers is commonly used, the float actuating a pointer or pen-arm. For electrical telemetering, direct use may be made of the variable h; the mercury level itself. There will now be described two systems which do away with mechanical floats and convert mercury level variations into variations of the current flowing in the interconnecting line.

[2] *Instruments*, August 1929, Pages 291-292.
[3] U. S. Patent No. 1,633,973. P. A. Borden. June 28, 1927.
[4] *Instruments*, December 1929, Pages 425-432.

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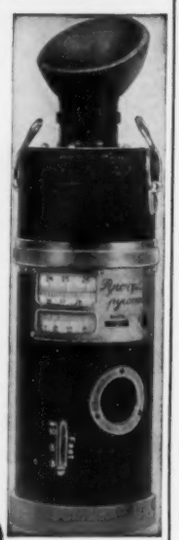

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Bailey

Fig. 44-9 shows the general principle of the Bailey Meter Co. system: A leg of the core of a small transformer passes through one of the two mercury chambers, so that the mercury forms a short-circuited secondary around the core. The primary winding is supplied with alternating current through the

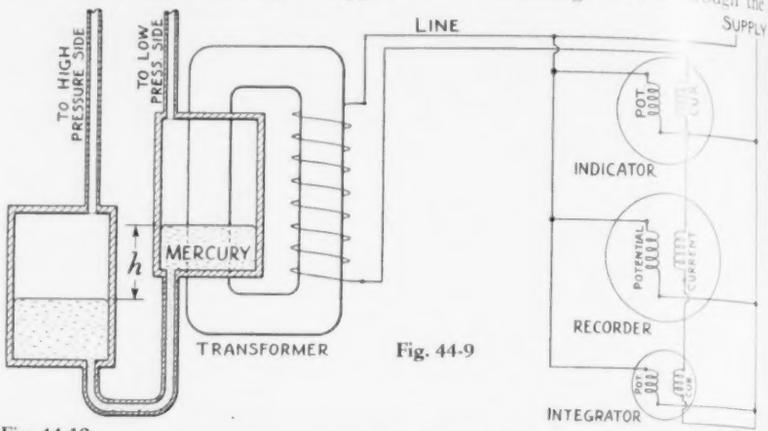
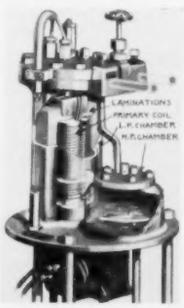


Fig. 44-9

Fig. 44-10



interconnecting line from the receiving station. With variations in mercury level the equivalent resistance of the transformer is changed, so that the current in the line becomes a measure of h and hence of the rate of flow. Fig. 44-10 shows the actual form of a Bailey transmitting section: the primary coil is mounted on the middle leg of a three-legged core-type transformer, and the mercury ring is formed around this middle leg and the primary coil. A wattmeter type of movement at the receiving end measures the line current and is graduated in terms of rate of flow. At the same time a registering instrument of the a-c. watthour meter type may be placed in the circuit to provide an integration of the total flow.

Republic

In the Republic Flow Meters Co.'s system, Fig. 44-11, the column of mercury in one of the chambers of the mercury manometer engages successively the ends of a group of over-hanging steel rods of different lengths which form the terminals of a calibrated rheostat (actual form shown in Fig. 44-12). The

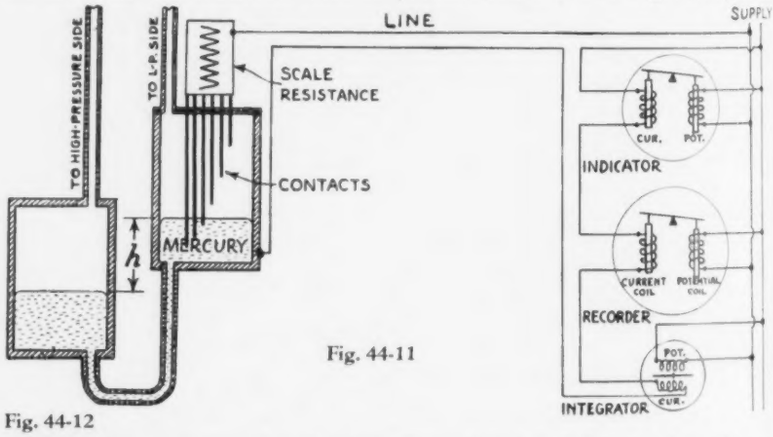
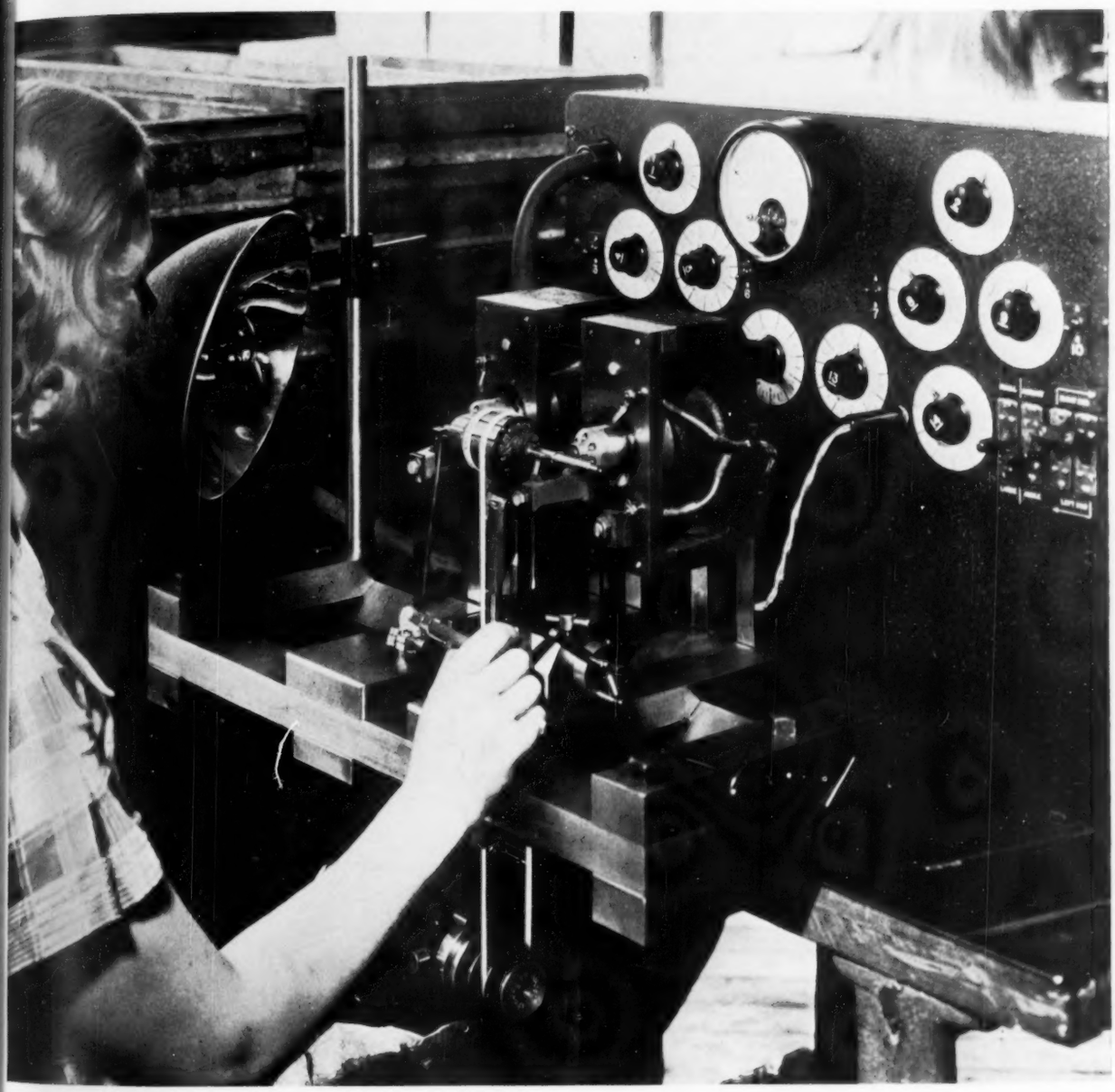


Fig. 44-11

Fig. 44-12

manometer thus introduces direct variations in the resistance of the whole line and governs the flow of current in the circuit. The receiving instrument has a ratio-meter or ohm-meter movement similar to the crossed-coil type (see *Instruments*, March 1934, Page 55) in which the reaction due to current in the line is opposed by that due to the line voltage, the pointer assuming a position representative of the ratio of the two. Integration is accomplished by a meter operating on the principle of a watthour meter, except that the permanent magnet is replaced by an electromagnet energized from the line, thus tending to eliminate errors due to variations in the supply voltage.

INSPECTION and TESTING



PRODUCTION BALANCING OF MOTOR ROTORS AT WESTINGHOUSE E. & M. CO.

See Article on Pages 228-231

Electromagnetic Deflection Methods for Cathode-ray Tubes

Third part of "The Cathode-ray Oscilloscope and Its Applications" being published serially in *Instruments*. This series began in the July 1935 issue.

By RALPH R. BATCHER

Radio engineer; cathode-ray and electronic application specialist, Hollis, L. I., N. Y.

ELECTROMAGNETIC DEFLECTION SENSITIVITY

Although it is impossible to determine accurately the absolute calibration factor for electromagnetic deflection from a theoretical study, an analysis of the problem may be of interest. Any conductor carrying current is acted upon by a lateral force when located in a transverse magnetic field. As previously shown, the cathode ray stream is equivalent to such a conductor and carries a current equivalent to eV, where e and V have the same meaning as in the electrostatic deflection principles which were analyzed in the preceding article.

The deflection due to the external field,

$$d = \tfrac{1}{2} \text{ acceleration} \times (\text{time})^2 \qquad (1)$$

$$\text{Acceleration is equal to } \frac{\text{current} \times \text{flux density}}{\text{mass}} = \frac{e}{m} VB$$

The time factor has been previously discussed, and equals l/V, where l is the length of that portion of the electron's path that is within the magnetic field.

Substituting these values in (1) gives:

$$d = \frac{e V B l^2}{2mV^2} = \frac{e B l^2}{2mV}$$

The velocity V of the electrons is approximately equal to $6 \times 10^7 \sqrt{E_a}$, therefore

$$d' = \frac{0.149 B l^2}{\sqrt{E_a}} \qquad (2)$$

This value of d' indicates the total deflection in centimeters found at the point where the ray emerges from the field. The actual curve of the path is a parabola, and the deflection is proportional to the square of the distance the ray has traveled in the field. From geometrical relations of such curves it will be found that a tangent to the curve at the point where the ray leaves the field is equal to $2d'/l$.

Since the ray travels on in the same straight line, it eventually reaches the screen with a total deflection equal to $2L/l$ times the deflection indicated by (2). Therefore, the total deflection

$$h = \frac{0.298 B l L}{\sqrt{E_a}} \qquad (3)$$

In the above analysis the assumption was made that the field had a constant intensity for the axial distance l and then dropped abruptly to zero. Such ideal conditions are rarely found with applied magnetic fields. In the case of the earth's field, the intensity is constant over the whole length of the tube.

Equation 3 has also been plotted as a nomographic chart, Fig. 1, used as follows: A line intersecting the L and l scales at their respective values will intersect the center line at some point. Another straight line through this point and the E_a scale at the point corresponding to the anode voltage, will intersect (if extended) the h/B scale at the value that shows the deflection to be expected in centimeters per gauss.

The power losses for a given deflection are much greater with magnetic control than with electrostatic control. Part of this is due to the increased efficiency of internal deflection plates over external coils. A comparison of the above equations with those in the preceding article will indicate that this relative difference decreases as the anode potential increases. This may be an important consideration when great fluorescent brilliance is required with high electron velocities, as in television applications, and when photographic records are required. Increasing the anode potential from 400 to 4000 volts has a marked effect on the brilliance. While the electrostatic deflection sensitivity has been decreased to 10%, the electromagnetic sensitivity to only about 32%.

MAGNETIC DEFLECTION COILS[1,2]

Practical considerations in the design of magnetic deflection coils are, that greatest sensitivity be obtained with the minimum IR drop in the coils. In qualitative measurements, some distortion (lack of linearity between B and the deflection) can be tolerated, but when quantitative results are required, the field should be symmetrical about the axis of the tube.

Since the deflection coils are generally placed alongside the tube and not far from the anode, the actual jet displacement required to produce screen-wide deflection is rather small. Consequently, if the coils are centered on a diameter of the tube, the field will be substantially constant over the limited space near the axis of the tube in which the beam operates. The coils are generally placed in planes parallel with a pair of internal deflec-

[1] Thompson. Magnetic Deflections. *Philosophical Magazine*, Vol. 18, 1909, pages 821-844.

[2] Perry & Chaffee. Measurement of e/m. *Physical Review*, Vol. 36, 1930, pages 904-918.

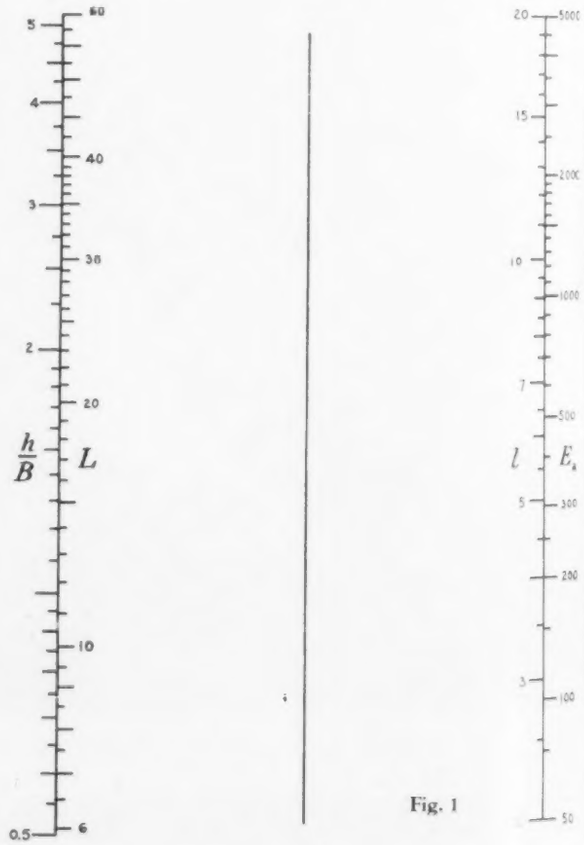


Fig. 1

tion plates in which case eddy currents and magnetic effects induced in the latter may affect the field, unless the plates are non-magnetic and have high electrical resistivity.

Two additional types of distortion come from the component of flux that is parallel with the axis of the tube, and from the opposing effect of the returning flux outside of the coil. The former might produce a small variation in the velocity of the jet as it moves from one side of the center line to the other.* The latter effect produces a counter-deflection having a value that is proportional to the deflection. If the total deflection due to the field is small, neither of these items is important. A large axial component of magnetic flux may produce distortion due to changing the velocity of the ray and to the rotation of the axes. This effect will be analyzed in a later article devoted to focusing.

The axes can be rectified by rotating the coils around the tube as required. When both magnetic and electrostatic deflections are used at the same time, it may be desirable to apply these fields to different points along the path of the ray.

Greater efficiency will be obtained by using a rectangular winding form for the deflection coil construction. The length of the central opening may be three or four times its width in which case the coils are mounted so that this long dimension is parallel with the axis of the tube. Figs. 2 (Westinghouse Elec. & Mfg. Co.) and 3 (an arrangement of the writer's) show examples of rectangular coil arrangements.

*The effect of this factor can be briefly summarized as follows: The initial direction of the jet is toward the screen. The jet is deflected upon entering the field (say, upward). It is then acted upon by additional forces due to this upward deflection; one along the axis of the tube (which only alters the axial speed) due to the cutting of the parallel flux through the coils; and the other force-parallel to the axis of the coils—caused by the vertical movement of the jet through the leakage field of the coils (the field parallel with the axis of the tube). When the electrons enter the latter field, the deflection is opposite to that which later occurs when they leave the field, and the resulting distortion would be balanced out if the deflection sensitivity was the same at both points (which may not be true).

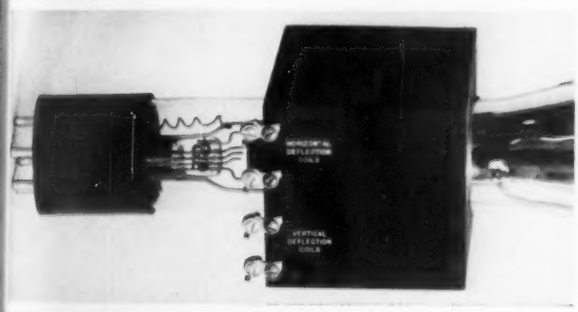


Fig. 2

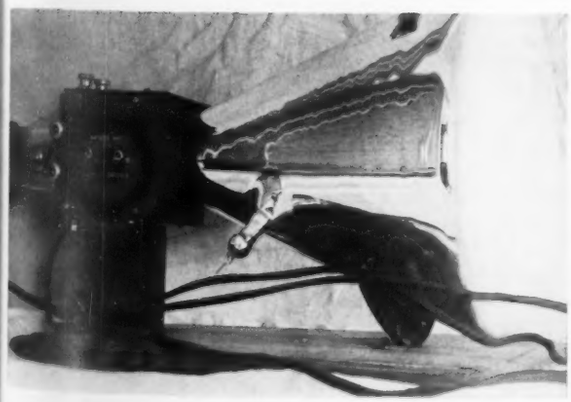


Fig. 3

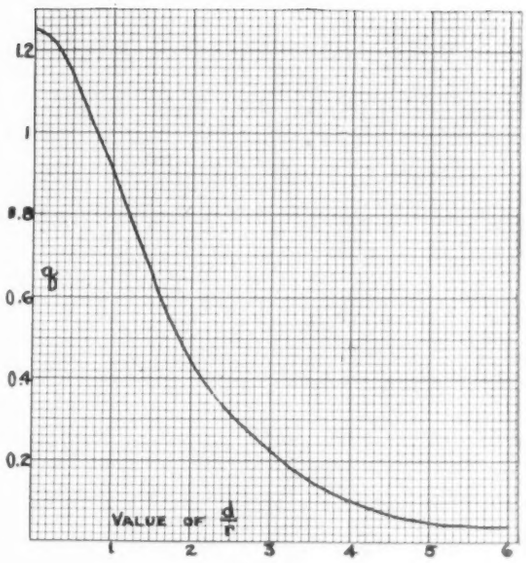


Fig. 4

FIELD STRENGTH DETERMINATION

In Equation (3) the factor B represents the average value of the flux density through which the jet travels. The actual value at various points may vary over wide limits, and may even be negative at certain portions of the path of the rays.

In computing the value of B for a given set of coils the relation

$$B = \frac{0.4\,\pi\,ni}{\lambda}$$

has often been used. However, the length of the flux path λ can only be roughly estimated. It may be shown, however, that if each coil is circular and has n turns (bound sufficiently close together into a small bundle so that a mean radius can be assumed for all the wires) the field due to both coils at a point midway on the common axis is (where r and d indicate the length of the coil radius and the distance between the coils respectively, in centimeters):

$$B = \frac{0.4\,\pi\,r^2\,ni}{\sqrt{\left[\left(\frac{d}{2}\right)^2 + r^2\right]^3}} = \frac{n\,i\,q}{r}$$

In Fig. 4 the values of q have been plotted, where

$$q = \frac{0.4\,\pi\,r^3}{\sqrt{\left[\left(\frac{d}{2}\right)^2 + r^2\right]^3}}$$

It is to be noted that the direction of curvature for the value of q changes at $d = r$ and the value of q at this point is substantially linear with respect to small movements of the point of reference. A system of coils whose radius is equal to the spacing will thus produce the most uniform field and the least distortion.

DEFLECTION COIL LOCATION

For magnetic deflection when high frequencies are applied, the two equal coils are placed on either side of the tube at right angles to one pair of deflection plates to prevent undue losses and distorted fields due to circulating currents being set up in the plates. Although the charge which collects on the inner surface of the tube usually acts as a shield, preventing the potential drop across the coils from producing false deflections, it often is desirable—as an additional precaution—to connect the coils in parallel.

Fig. 5

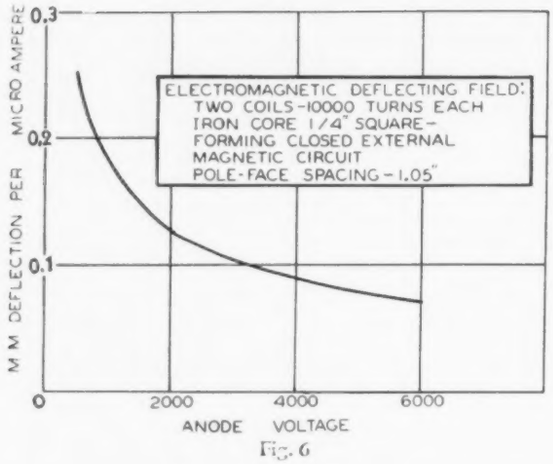


Fig. 6

It usually is necessary to maintain the normal potential of the coils with respect to ground at some definite value. That is, the deflection coil circuit should not "float" above ground potential. As previously mentioned, the anode and unused deflection plates should be grounded.

Such coils energized with a battery may also be used to shift the axis of the curves in any one direction, to center the useful portion of the figure, or to permit the delineation of several curves normally superposed. Throwing a switch will make the shift quickly and accurately to some predetermined location with this means. The advantage of this method over the use of a permanent magnet, is that the latter cannot be shifted just the right amount quickly and conveniently. Moreover, its field is not definitely confined, so that the shift is oblique to the desired direction. It should be remembered that the deflections take place in a direction perpendicular to the axis of the coils. Fig. 5 shows a typical design of air-core deflection coil assembly, as constructed by the writer.

Practically, deflection coils will never prove universally satisfactory for general use until cathode ray tubes are manufactured in which all deflecting plates and other electrodes are formed of non-magnetic materials. At present these elements frequently retain some magnetism, which interferes with focusing and causes the spot to seek a new "zero" location that is not in the center of the screen.

DEFLECTION COILS WITH IRON CORES

The question may be asked as to why the usual deflection coils are designed with an air core. The RCA technical bulletins have described deflection coil arrangements with iron cores, in which the sensitivity is increased possibly ten times. The curve and description of coils recommended for their 903 type tube are reproduced in Fig. 6. The greatest disadvantage with this arrangement is the ease with which the core becomes permanently magnetized so that the spot does not return to the original center after current of any type is passed through the coils, due to the retentivity of the core. The use of Permalloy in the core should help out in this difficulty but actual tests have not been made by the author. However, a magnetic deflection system made with high-silicon steel which was thoroughly annealed before assembly, is shown in Fig. 7. The deflection sensitivity with an RCA 906 tube was a two-inch movement per milliamp. change, but the retentivity still was a disagreeable feature. The core was of large cross section ($\frac{3}{4}'' \times 1''$) to reduce the flux density. The coils had approximately 20,000 turns of No. 32 wire.

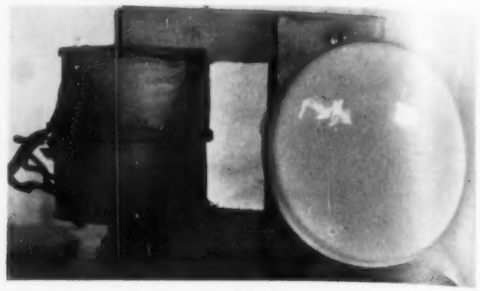


Fig. 7

Fig. 8

A number of tubes have been designed for magnetic deflection, *i.e.*, without deflection plates. A common arrangement is to constrict the tube at the desired point so that the air gap in the magnetic field from the deflection coils is reduced, and a shorter magnetic return path.[3] In order to be most effective, the internal diameter of this neck should not be much larger than the usual separation given deflection plates (Fig. 8) and so the tube is somewhat more fragile.

DEFLECTION DUE TO EARTH'S FIELD [4, 5, 6]

The field of the earth will affect the normal position of the spot. Although this field is relatively weak (of the order of 0.2 gauss) it affects the beam throughout its whole length. The displacement is not large enough, however, to cause concern. Analysis will show that (in the U. S.) if the axis of the tube is vertical the spot will be deflected toward the East. If the tube is rotated on its own axis, the spot will remain stationary if its displacement from the center of the screen is due to external fields. If the spot moves around with the screen, the chances are that the displacement is due to misaligned elements, or magnetized deflection plates or support wires. Practical applications of the utilization of the deflection due to the earth's field will be taken up in a later article.

[3] Lubke. Frequenz electrischen Wellen Wechselstromkurven. *Archiv für Elektrotechnik*, Vol. 6, 1917, pages 161-164.
[4] Knipp & Welo. Measurement of the Earth's Field. *Philosophical Magazine*, Vol. 32, 1916, page 381.
[5] Bruche. Experimente zu Stormers Polarichttheorie. *Physikalische Zeitschrift*, Vol. 31, 1930, pages 1011-1016.
[6] Bruche & Ende. Fadenformige, sichtbare Electronstrahlen. *Zeitschrift für Physik*, Vol. 64, 1930, pages 186-190.

NEW INSTRUMENTS

In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions.

When writing to manufacturers directly, please mention this department as your source of information.

Or write to Information Section, Instruments Publishing Company.

Air-operated Controllers

On its 75th anniversary, The Brown Instrument Company announces a new and complete line of recording and indicating air-operated controllers for temperature, flow, pressure and liquid level. Outstanding among them is the "Air-o-Line," Fig. 1, with 1% to 150% throttling range and automatic reset. This control system is said to recognize and correct for the extent, rate and direction of departure from the control point. Thus capable of "full automatic control," it will maintain a condition within extremely close limits. Principal feature: the simplicity of the means provided for "tuning in" the controller to the specific process characteristics without interruption to automatic control. Throttling range and automatic reset dials are instantly adjustable with a screw driver, without removing the chart plate. (See Fig. 2.) Indicating and recording thermometer-type temperature controllers are available for temperatures within limits of —40°F. and +1200°F. Potentiometer-type controllers are available for temperatures within limits of —300°F. and +3400°F. Two types of flow controllers and liquid level controllers are also offered: the inductance bridge type and mechanical type. Indicating and recording pressure controllers are available in ranges from 30" Hg. vacuum to 3000 lbs./in.² gage.

In addition to the "Air-o-Line," three other types of air-operated controllers are included in the new line. These are, the "Full throttler" (with 1% to 150% throttling range and manual reset), the "Throttler" (with 1% to 10% throttling range and manual reset) and the "On-Off Controller" (for 2-position service).

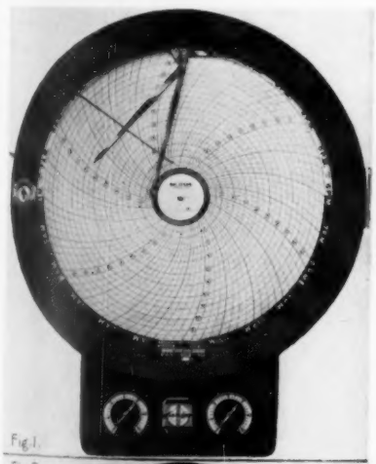


Fig. 1.

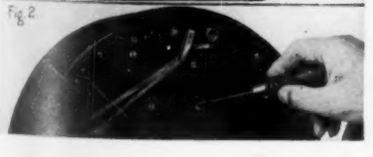
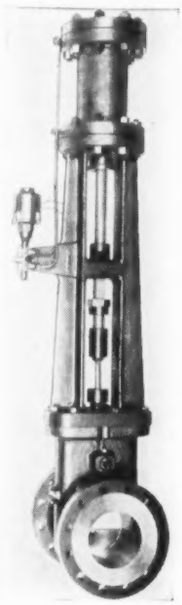


Fig. 2

Automatic Adjustable Orifice

A two-rate orifice announced by the Bailey Meter Co. automatically shifts in accordance with major changes in rate of flow, so that when installed in a pipe line and connected to a standard recording and integrating fluid meter, it greatly widens the measuring range of the meter. It is similar in appearance to a hydraulically-operated gate valve. The gate, however, is a sharp-edged orifice segment (coefficients accurately determined) which rests in either one of two definite positions, by reason of movable stops limiting the stroke of the hydraulic piston. This piston is operated through the solenoid valve seen at the left of the photograph. This valve is commanded by contacts made in the recording meter whenever the differential across the orifice reaches a predetermined minimum or maximum. Simultaneously with this automatic change of capacity, the integrator drive is shifted to a second Warren motor so it continues accurately to register the total flow; and the contactor energizes also a small solenoid which operates an auxiliary recording pen to show the proper multiplying factor to be applied to the corresponding flow record on the chart. Under an increasing flow condition, the orifice shifts position at a higher rate of flow than it does on decreasing flow. This overlap prevents constant shifting when the flow holds closely to the midpoint. The metered fluid itself (if it be a clean, non-corrosive and relatively cool gas or liquid) can be used to drive the hydraulic piston. Ordinary city water can be used, too.



Condenser Kit

To facilitate the assembly of the Thordarson combined condenser capacity and leakage tester for which foundation unit, transformer, choke, potentiometer, knobs and other components have been available for some time past, the Aerovox Corp. announces a special kit of condensers, consisting of the seven Aerovox condensers specified by the Thordarson designers, of the exact capacities and voltages called for.

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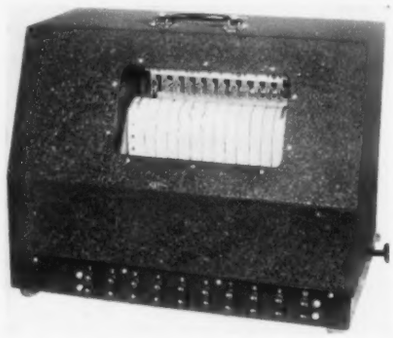
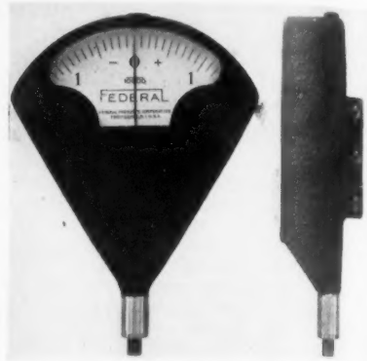
Multiple-pen Recorder

Developed originally for studies of functioning of automatic telephone exchanges, the "Autelco" Multiple-pen Recorder announced by the Automatic Electric Co. is suitable also for use as an "on-off" time-operation recorder in manufacturing plants and laboratories. It comprises 12 electromagnet-actuated syphon pens fed from a common inkwell, producing parallel records ½" apart, on a 7" unruled strip chart driven at constant speed by a synchronous motor and gear train. Records are of the "side jog" type, the lateral pen movement being ⅛". Change gears permit chart speeds from 25" per minute to 1" per day. Chart paper comes in 150-ft. rolls. Time marks may be produced thereon by connecting one of the pens to a source of timed impulses governed from a standard clock, or by operating two pens from a "Date and Time Recorder" whereby coded sets of jogs are produced which correspond to month-and-day on one pen record and to hour-minute-second on the other. "A.m." and "p.m." code jogs can also be produced by proper pulses from the "Date and Time" auxiliary device. The pen magnets (adapted from an "Autelco" relay) can operate the light metal syphon pens fast enough to record operations occurring at intervals <0.1 second. Electrical groupings of pens permit increasing the capacity of the 12-pen recorder to 30 operations: the first 10 pens standing for final digits, the eleventh for "+10" and the twelfth for "+20." These hook-ups permit also the recording of variables, among which the makers list "flow of water, air, etc. . . . temperature, concentration, speed, etc." The instrument measures 15½"×9"×12¼" high and weighs approx. 30 lbs.



Dial Indicator

Federal Products Corp. announces "Model 866" Clear Vision Type Indicator, with its 0.001" divisions approx. 0.1" apart; also "Model 95" with a full 0.2" between divisions. This new form is especially designed for inspection, the limited dial being quickly spoted without eye-wandering: the inspector merely spots the zero point and notes the deviation of the needle, so that confusion is done away with in rapid work.



Stroboscope Tachometer

Aptly styled "Strobotac," a portable (12 lb.) instrument announced by the General Radio Co. is an intermittent-light-source stroboscope with a range extending from 600 to >12000 flashes per minute, the setting being by a vibrating reed whose fundamental calibration is made at any time by direct comparison with the 60-cycle a-c. supply which operates the device. *Other features:* When the Strobotac is held in one's left hand (Fig. 1) all controls are on its right-hand side. Tripod mounting is provided for. Choice of three frequency controls: (1) by knob reading in r.p.m.; (2) by external contactor to obtain absolute synchronism with observed mechanism; (3) by power-line frequency. Accuracy when used for measuring an unknown speed is ± 2%.

Fig. 1

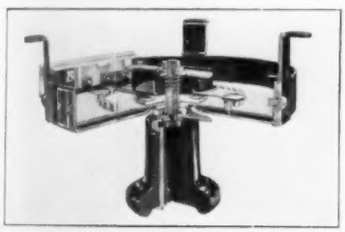
Fig. 2

Air Bell for Orsats

The Ellison Draft Gage Co. announces an air bell designed to replace the rubber air bag in Orsat gas analyzers. It consists of a floating bell in a cup filled with water up to the bead. The weight of the bell provides the necessary air pressure which is constant for the full range of the bell movement, approx. ¾" water head for the 50 cc., and 1" for the 100 cc. analyzers. The speed of operation of the instrument is said to be increased beyond that possible with air bags. Before beginning the test, and with the solutions standing at the rings in the capillary tubes, the bell is adjusted to stand even with the top of the cup or up to ⅛" above the top, by holding the bell with one hand and with the other sliding the tubing over the single point adapter. To compensate for the contraction of the air volume in the bell by the solutions absorbing the oxygen, a clearance of ¾" is provided at the bottom of the cup. The cup is held in place by a clip and is easily detached for filling and draining the water.

Field Rheostats

Ward Leonard Electric Co. announces field rheostats of new construction with a pressed steel plate, which forms a light but rigid base. The resistance element to which the contacts are welded is enveloped in a fused-on vitreous enamel. The steel shaft turns in a graphitized bronze bearing burnished to close tolerances. All parts are keyed and locked into slots milled across each end of the shaft. The functions of current carrying and contact pressure are separate. A rigid, hard copper contact arm is held against the contact by means of a large heat-treated coil spring. The contact arm is double-ended, giving a balanced construction with almost 360° travel. Spacings and creepage distances meet all requirements for 600-volt service. Underwriters' listing for all sizes. Unusual requirements can be met.

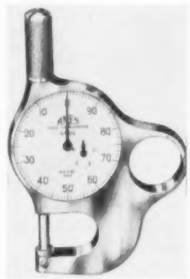


High-speed Counters

For the ever-increasing speeds required in testing, coil winding, and fast production machinery, the Durant Mfg. Co. has brought out 5000-r.p.m. counters fitted with ball bearings and embodying a new worm drive giving smooth operation and continuous motion, said to eliminate sudden shocks or jerks within the mechanism. Energy consumption required for registering on these counters being minimized, they are adapted to light-action recording. The standard counters count one for each revolution of the drive shaft; other ratios can be provided. Rotation is clockwise or counter clockwise. The counters subtract when reversed. The black digits on white background are easy to read. Drive shafts 5/16" diam. extend 1½" from the case at end, top, bottom, front, or rear as specified. Both resetting and non-resetting models are available.

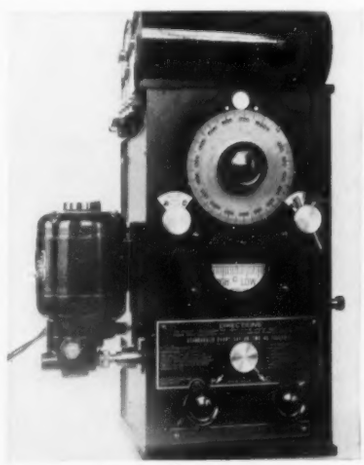
Dial Micrometer

Thinness and compactness distinguish the new "No. 23" dial micrometer announced by the B. C. Ames Co. It weighs 5 oz. and is said to fit the vest pocket as readily as a watch. Its measuring capacity it 0.5". To open or close the ¼" diam. anvils, the knurled barrel at the top is turned with a finger motion of the hand holding the gage. The main dial is graduated in thousandths and the main hand makes one revolution for a 0.1" anvil movement; the small dial is graduated in tenths and the small hand makes one revolution for the 0.5" capacity. The rustless case bears a decimal conversion table on its back.



Control Pyrometer Drive

For installations where its potentiometer control pyrometers are to be used singly or in pairs, The Foxboro Company has developed an improved type of motor drive unit, "Type H," comprising a ball-bearing enclosed motor and a double worm and gear speed-reducing system packed in lubricant.



THWING

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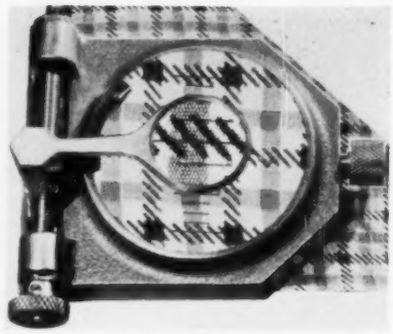


Inspection Magnifier

Many uses in connection with routine inspection and research work are listed in the announcement by K. G. Frank of the new "Compound Inspect-O-Scope" which has a greater magnifying and resolving power than the simpler previous model. It consists of a condenser lens, an eyepiece lens provided with a vertical focusing screw, and a frame with perpendicular adjustments. The scale facilitates thread counting and other measurement purposes. Accessories announced include color filters and a flashlight for use in dark places. Under normal light the condenser lens affords an amply illuminated field.

Paint Flow Regulator

Binks Mfg. Co. announce the "47A Material Regulator" which permits control over paint consumption in spray paint handling systems. Individual regulators are installed at each point on the pipe line where a tap is taken off for a spray gun, and set by the paint superintendent with a key. It is said that paint viscosity once determined can be adhered to without interference by operators who like to add thinner to suit their own convenience; also that the regulator insures better finish as the paint is always delivered under correct pressure and is applied in proper thickness.

Interference Analyzer

The Sprague Interference Analyzer announced by the Sprague Products Co. is said to make possible the prompt location and elimination of all types of radio interference. It is connected into the circuit of the suspected electrical appliance. Then, with custom[illegible] radio (or serviceman's portable set) turned on, different filter banks are connected into the circuit by means of the selective switch until the one is found that eliminates the noise most effectively. The Analyzer aids also those who install oil burners, etc., by enabling them to select and install the necessary filter material then and there.

Watthour Meter Tester's Pocket Calculator

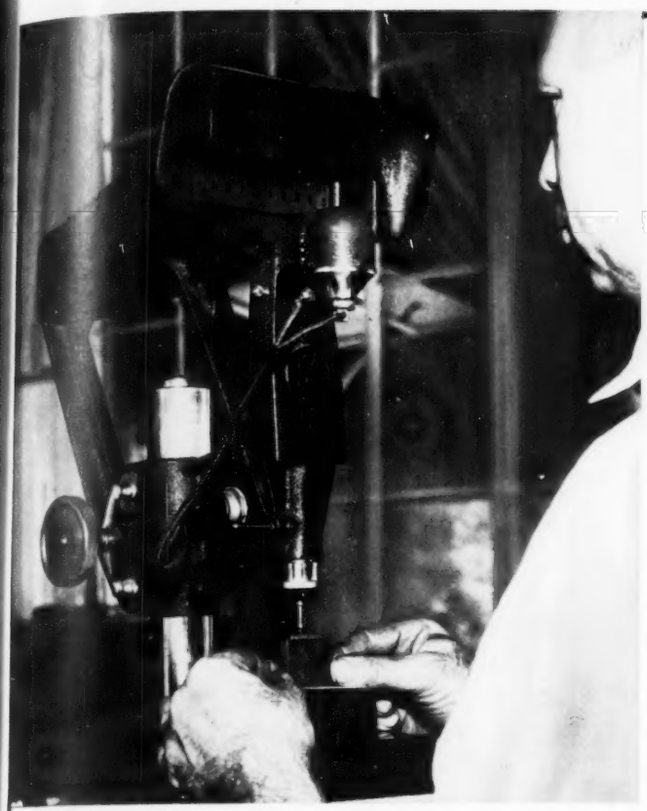
Errors of computation are eliminated in the testing of watthour meters against Standards, the routine speeded up and many arguments prevented in connection with "complaint tests," through the use of the Bangh Calculator announced by the Herman D. Steel Co. It is a form of slide-rule measuring 2¾x5⅞". It comprises a fixed envelope and a slide, with openings on both sides of the former, whereby columns of figures on the envelope and slide are brought into proper relation for quick reference.

BANGH REVOLUTION AND PER CENT REGISTRATION CALCULATOR
METER UNDER TEST
LOADS FOR TESTING
WHEN STANDARD RUNS
PER CENT REGISTRATION OF METER UNDER TEST
DISTRIBUTED BY HERMAN D. STEEL CO

There are no scales: the quantitative data are all in the form of figures. It is said that only one setting of the slide is required for "complete information on all sizes of each type of meter." Four calculators are available, each for certain Standards with various coil combinations, and the complete set covering practically all meters used in American practice.

Small Oil Blast Circuit Breaker

An oil blast circuit breaker, "Type FK-42," especially applicable where space is limited as in industrial plants, is announced by the General Electric Co. It is rated 600 amps, 7500 volts; 800 amps., 2500 volts; and 25,000 kva. interrupting rating. All designs may be manually or electrically operated; are double- and triple-pole single throw, with all poles in a single rectangular welded plate steel tank. Provision is made for mounting directly back of panels, or in switch houses or metal-enclosed switchgear. Features: compact construction; silver-to-silver main contacts protected by arcing contacts; oil blast baffles for high-speed interruption; "Herkolite" bushings; internal mechanism with entire absence of external moving parts. A complete line of accessories, including overcurrent trip coils, both instantaneous and inverse time delay (for manually or electrically operated breakers), undervoltage devices, auxiliary switches, steel supports, etc., will be available.



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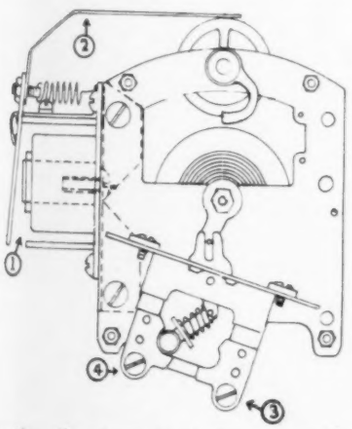
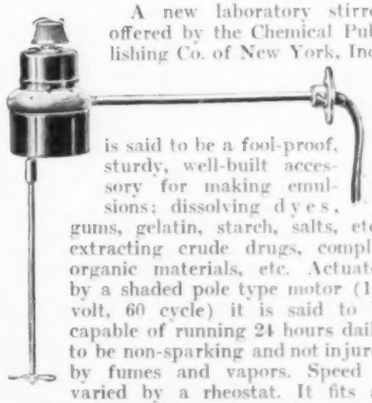
SEE THE JOHANSSON DISPLAY AT THE CLEVELAND MACHINE TOOL SHOW. BOOTH A-201.

Thermal-load Timer

The Walser Automatic Timer Co. announces that its standard "No. 80 Series" timers may now be equipped with a magnetic coil and brake finger device to record the operating time of heating appliances at definite temperatures. The illustration shows its application. In operation, the timer is set for any predetermined time interval. This closes timer switch circuit 3 to which the appliance heating coil lines are connected through relay. When the temperature reaches the point at which the thermostat has been set, the thermostat circuit controlling magnetic brake coil 1 is closed, thereby lifting brake 2 off the escapement wheel and allowing the timer to operate. After the timing interval has elapsed, the timer opens circuit 3 (controlling the heating coil) and closes circuit 4 to which a signal light or bell may be connected. When the heat in the appliance falls below the thermostat setting, the thermostat will open the circuit to the magnetic coil. Signal lights or bells can be used in the heating coil circuit to indicate a closed circuit on the appliance heating coil; also, in the thermostat circuit to indicate that the heat has reached a definite temperature; and in the signal circuit to indicate that the timing interval has expired.



Laboratory Stirrer



A new laboratory stirrer offered by the Chemical Publishing Co. of New York, Inc., is said to be a fool-proof, sturdy, well-built accessory for making emulsions; dissolving dyes, gums, gelatin, starch, salts, etc.; extracting crude drugs, complex organic materials, etc. Actuated by a shaded pole type motor (110 volt, 60 cycle) it is said to be capable of running 24 hours daily, to be non-sparking and not injured by fumes and vapors. Speed is varied by a rheostat. It fits an ordinary clamp holder or may be screwed to a shelf or wall. The shaft and propeller are furnished in chromium plate or Monel.

Floor Model Blueprinter

A floor model of the Angstrom Lamp Blueprinter announced by Milligan & Wright Co. is of 18"x24" capacity and has a novel arrangement for the washing and fixing trays and drying boards provided in the base (photograph shows trays extended for use). Floor space required is thus only 28x30". The incandescent lamp can be plugged into any 110 volt a.c. or d.c. light socket, yet produces prints in ¾ to 1½ minutes depending upon the drawing and paper used. A time switch cuts off the current at the end of the exposure selected. It is claimed that prints ordinarily costing 10c outside can be produced for about 3c on this new Model 200.

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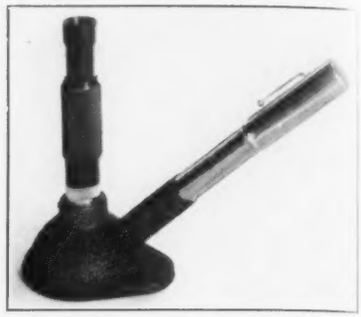

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GENERAL RADIO COMPANY
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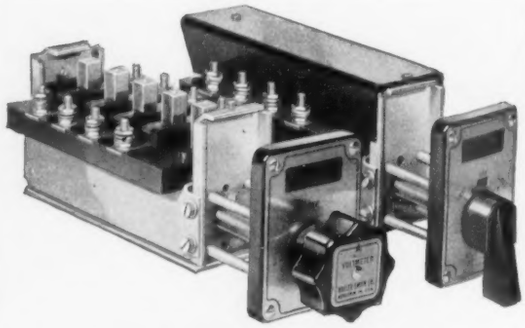

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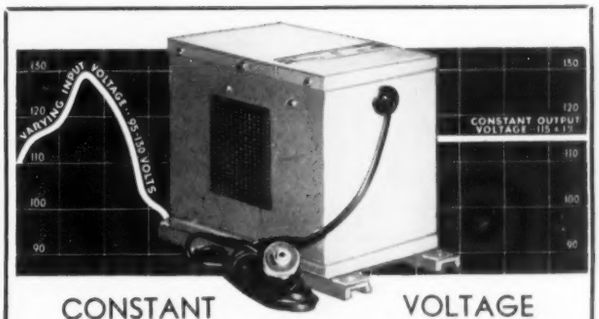

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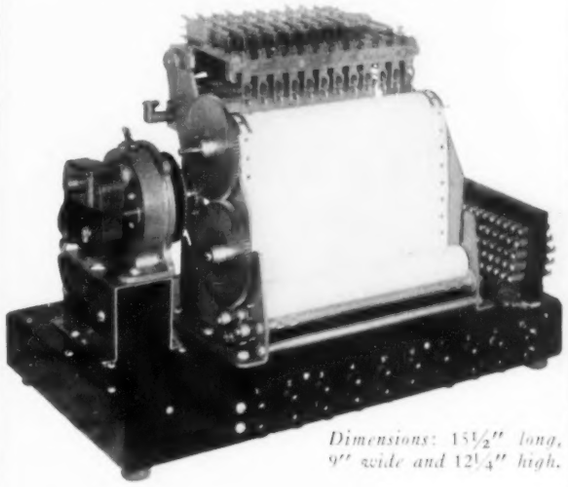

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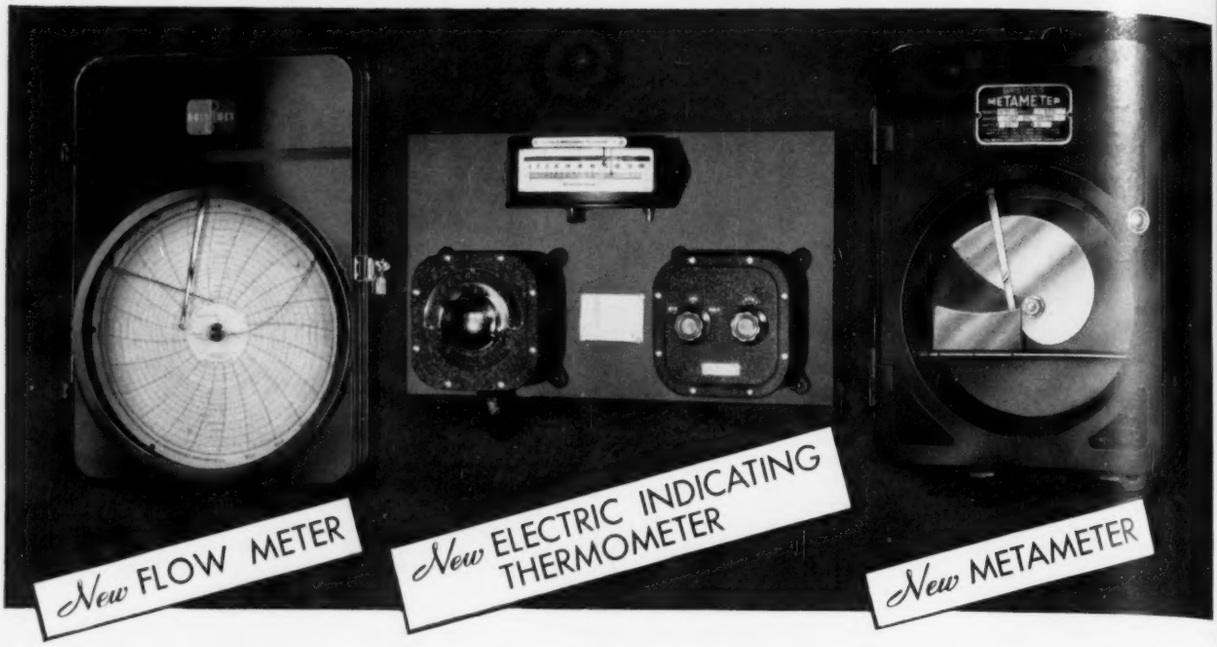

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